MINISTRY OF TECHNOLOGY

Report of the Committee of Enquiry on Pressure Vessels

Volume 1 Report

Chairman: Mr. R. W. Nichols

LONDON
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Appointment, Terms of Reference and Membership

The Minister of Technology appointed an independent Committee of Enquiry on Pressure Vessels on the 9th December, 1966 with the following terms of reference:

> **'To recommend ways of improving pressure vessel technology, including standards, design and manufacture.'**

The Minister appointed as Chairman of this Committee, Professor J. L. M. Morrison, CBE, DSc, C Eng, FI Mech E, Vice President of the Institution of Mechanical Engineers and Chairman of BSI Engineering Division Council. Unfortunately Professor Morrison was taken seriously ill shortly after the first meeting of the Committee, and the Minister appointed Mr. R. W. Nichols, B Met(Hons), FIM, M Inst W, Deputy Head, UKAEA, Reactor Materials Laboratory, Culcheth, as Chairman of the Committee in his place. On recovery from his illness, Professor Morrison returned as a member of the Committee.

The other members appointed to the Committee were:

Mr. A. H. Goodger, MSc Tech, FIM, FRIC, F Inst W; (Consultant, formerly Technical Chief of the National Boiler and General Insurance Co.).

Dr. K. J. Irvine, BSc, PhD; (Metallurgical Research Manager, United Steel Companies Ltd.).

Professor W. R. D. Manning, MA, C Eng, FI Mech E, MI Chem E; (Consultant and Visiting Professor to Loughborough University of Technology).

Mr. M. J. Noone, OBE, C Eng, FI Mech E, MI Chem E, MI Gas E, F Inst Pet; (Group Chief Executive, Whessoe).

Dr. P. J. Palmer, DSc, PhD, MSc, DIC, ARCS, C Eng, FI Mech E, AFRAeS, A Inst P, M Inst W, MBIM, Mem ASME; (Managing Director, BOC-AIRCO).

Mr. L. F. Robinson, AMICE, AI Arb; (Managing Director, Power-Gas Corp. Ltd.).

Mr. C. S. Tanner, BSc, MSc, C Eng, FI Mech. E; (Consultant, formerly Engineering Manager, Agricultural Division, ICI Ltd.).

Joint Secretaries: Mr. J. S. Linton, C Eng, MI Mech E, AFRAeS; (Ministry of Technology).

Dr. H. J. Ivey, BSc, PhD, C Eng, MI Mech E., FBIS; (Ministry of Technology).

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*Vol. 2 which will also be published by H. M. Stationery Office, is in the course of preparation and will follow.

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To the Right Hon. Anthony Wedgwood Benn, M.P.,
Minister of Technology

In December 1966 you appointed us to conduct an enquiry on pressure vessels with the terms of reference as given in our letter of appointment. I now have pleasure in submitting our Final Report.

The Report has been prepared following careful consideration of all the evidence submitted to the Committee, including that obtained from a number of special surveys. Summaries of much of this background evidence and information are given in Appendices published separately from the Report. During the course of its work the Committee has attempted to consult and to take into account the views of the most relevant industrial sectors. In addition to an initial enquiry letter sent to some 80 organisations, a number of more specific investigations were undertaken. For example, problems on materials were pursued in detail with many individual fabricators, with the steel industry and with manufacturers of welding consumables. Companies in each of these industrial sectors studied criticisms made about products and services provided by their sectors and gave detailed replies. To quote another example, comments on inspection led the Committee to circulate preliminary proposals which were later revised on the basis of the replies received. The revised proposals on inspection were discussed at a special meeting with senior representatives of UK inspection organisations, and the final proposals given in this Report take their comments into account. Further details of the degree of consultation undertaken by the Committee are given in the 'Method of Working' section in the Report.

The Committee believes that swift action is necessary to improve further the efficiency and competitiveness of the UK pressure vessel industry. We hope therefore that the Report can be published quickly, so that the recommendations of the Committee can be discussed and acted upon without delay.

The Committee would like to assure you of its willingness to continue to help this important industry in whatever way it can.

R. W. NICHOLS (*Chairman*)
A. H. GOODGER
K. J. IRVINE
W. R. D. MANNING
J. L. M. MORRISON
M. J. NOONE
P. J. PALMER
L. F. ROBINSON
C. S. TANNER
J. S. LINTON } *Joint*
H. J. IVEY } *Secretaries*

25th October, 1968

Method of working

The independent Committee of Enquiry on Pressure Vessels first met on 18th January, 1967 and has held twenty-seven meetings. Its first action was to draft a general letter of enquiry detailing the main topics of interest and to invite specific comment on these topics. This letter was sent out on 2nd February, 1967 to 77 organisations, including Government departments and public bodies, professional institutions and trade unions, insurance and inspection organisations and trade associations. The response to this letter is shown in Appendix E. From these replies the Committee identified the main areas of comment; took steps to obtain further information on these areas, and drafted recommendations for improvement.

An area of great interest on which there was an obvious shortage of information concerned the economic situation of the UK pressure vessel industry, including details of its structure and of the trends in supply and demand in comparison with similar information on principal competing countries abroad. After interviewing representatives of several appropriate consulting and other organisations, the Committee arranged for an economic survey, involving collection of information both by questionnaires and by visits of specialists, to be carried out by an independent not-for-profit research institute. Throughout this work the institute had the assistance of staff from the Economics Division, Standards Division and Process Plant Branch of the Ministry of Technology. The progress and direction of this survey was controlled by the Committee through the Economic Survey Steering Group (with Dr. P. J. Palmer as Chairman). The Economic Survey Steering Group held eight meetings and reported on its activity regularly to the Committee of Enquiry. During the course of the economic survey over 1000 questionnaires were returned by UK firms, and 35 interviews were completed with major UK pressure vessel fabricators.

Similarly, the Committee commissioned the UKAEA Reactor Materials Laboratory to undertake a survey of Research and Development currently underway in the UK relating to pressure vessels and their manufacture. The survey also covered future R & D plans. The R & D survey was under the direction of Mr. R. W. Nichols, who reported on the survey regularly to the Committee. Questionnaires were returned by nearly 270 organisations of all types in the UK.

Information on various aspects of the materials used in pressure vessel fabrication was obtained by sending out questionnaires, to which 26 fabricators and trade associations replied. This was followed by a second set of questionnaires on the supply of steel plate, to which 12 steelmakers' trade associations (or conferences) and steel companies replied. A separate survey was undertaken on welding consumables, in which replies to questionnaires were obtained from a selection of 10 fabricators and 8 welding consumables manufacturers. These surveys were undertaken by the Committee Secretaries under the direction and guidance of Dr. K. J. Irvine.

Replies to the general enquiry letter contained many comments on inspection procedure in the UK, and a sub-committee (with Mr. M. J. Noone as Chairman) reviewed these replies and drafted proposals for changes in the present inspection procedures. The sub-committee circulated these proposals and obtained further comments from 28 interested organisations; several of these organisations also put forward alternative models for changes in the present inspection procedures. The Committee Secretaries reviewed for the Committee various inspection procedures applied in pressure vessel industries in other countries, as well as analogous schemes for other industries in the UK. This review included information on various procedures for the preparation and revision of standards; further information on the present procedure in the UK was obtained by correspondence with BSI.

With regard to design, the Committee commissioned papers from those of its members who had expertise on particular aspects. Arrangements were also made with the National Computing Centre for a survey to be undertaken of various aspects of the application of computers to the pressure vessel industry including design. The Committee also received additional reports and evidence on a number of technical topics from various sources, including the report of the 'Working Group on Welding Technology in the Pressure Vessel Industry' set up by the Ministry of Technology in 1966.

The Committee has spent considerable effort collecting and reviewing the evidence on all the topics indicated in the above paragraphs, and from this broad base has prepared its Report.

Chapters 1 to 15 are concerned with conclusions and recommendations of the Committee, and are supported by just sufficient information to indicate the background. The evidence and information supplied to the Committee is reviewed in Appendices E to U contained in Volume 2 of the Report (see page vii). References are given in the text of the Report to appropriate appendices where more detail may be found.

Acknowledgements

The Committee would like to extend its appreciation to all those organisations and individuals who, through so freely giving their time and experience, had made the present Report possible. All the organisations and individuals noted in Appendix A (Organisations submitting evidence) contributed in one way or another: by completing questionnaires, by submitting evidence, by providing statistical and other information, and by giving their views and opinions. Whilst it would be unfair to single out particular organisations and individuals for special mention, the Committee wishes to express its sincere thanks to all concerned.

The Committee also wishes to acknowledge its appreciation of the considerable help provided by various members of the staff of the Ministry of Technology.

Summary of recommendations

The pressure vessel industry represents an important and substantial part of the heavy fabrication sector in Britain. An active and efficient pressure vessel industry is believed to be essential for the further development of an industrially and commercially strong country. Such an industry not only plays a major role in developing skills in heavy fabrication in general, but is essential for the development of a variety of other important industrial sectors. These include nuclear energy, the organic and inorganic chemicals industries, petro-chemicals, mineral oil refining, power production, fertilizers and many others. A technically strong indigenous pressure vessel industry enables important 'user' industries to develop and expand. Furthermore, it is of great help towards the export of 'turn-key' chemical and other process plant resulting from the efforts of British contractors and chemical companies.

A viable and highly developed pressure vessel industry is usually regarded internationally as providing an index to a country's heavy engineering potential. All practical steps should be taken to ensure the British pressure vessel industry is as good as or better than those abroad. Such steps are likely to give good value for money, since large areas of engineering and industrial activity would be influenced beneficially at relatively small cost.

Whilst the British pressure vessel industry is one of the largest in the world, it is believed that speedy action is desirable and necessary to enable the industry to improve further its competitive position and to remain in the forefront of technical progress. This Report makes a number of detailed recommendations which would enable the industry to achieve an even greater competitiveness and technical ability, both of which will be essential in the markets of the future.

To assist in the above process the Committee of Enquiry recommends that action should be taken to improve further the British pressure vessel industry. Towards this end the Committee of Enquiry recommends:

On trade organisation and marketing

1. that a single body be created to represent the interests of all pressure vessel fabricators, and that all pressure vessel fabricators be encouraged to support this body; 3.13 (i) to (v)*

2. that the future demand for pressure vessels be forecast on a more detailed technical basis; 4.3

3. that the Government should encourage the use of public authority purchasing powers in a counter-cyclical manner to reduce the magnitude of fluctuations in demand on the pressure vessel industry; 4.8

4. that the Government be prepared to act quickly whenever 'dumping' is suspected; 5.5 (i) to (iii)

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* Paragraph numbers after each summary recommendation refer to the Committee's detailed recommendations in the text of the Report

5. that improvements be made in market information services, including export intelligence, relating to pressure vessels;
5.19 (i) to (iv)

6. that the Government considers how to improve the Export Credit Guarantee system;
5.19 (v) and (vi)

7. that steps be taken to ensure adequate communication between pressure vessel fabricators, contractors and end-users; 6.3

8. that the wider use be introduced of satisfactory production control techniques and of good interdepartmental communications within pressure vessel fabricators;
6.4 (i) to (iii)

9. that present methods of tendering and purchasing be improved:
6.7 (i) to (iii)

On management and industrial structure

10. that employers and the appropriate unions be encouraged to establish the principles of agreements to obviate demarcation difficulties, and to improve personnel relations and increase productivity;
7.10 (i) to (iv)

11. that Government redeployment policy and re-training facilities be used to ease the problems of obtaining skilled men for the pressure vessel industry;
7.15 (i) to (iv)

12. that fabricators be registered as competent to manufacture pressure vessels by given types, and that this register be published annually;
7.17 (i) to (iv)

13. that a comparative assessment be initiated of different techniques of welding, preparation and inspection of pressure vessels;
7.18 (i) and (ii)

14. that discussions be arranged as a matter of urgency between the Industrial Reorganisation Corporation and the pressure vessel industry on suitable steps towards rationalisation of the industry; these steps should include financial encouragement towards rationalisation including the provision of new fabrication shops;
7.3 and 7.24 (i) and (ii)

On materials

15. that suitable arrangements be made whereby the pressure vessel industry keeps the steel supply industry informed of its technical and other requirements, and that these be taken into account in re-planning present UK steel production facilities; 8.13 and 8.31

16. that delays caused by the replacement of defective steel plate be reduced;
8.16 (i) and (ii)

17. that the method of steel plate identification be improved and that prompt and full documentation of the plate be provided;
8.19 (i) and (ii)

18. that wider use of vacuum-degassed steel plate by fabricators be encouraged;
8.23 (i)

19. that satisfactory facilities be provided at the steelworks for ultrasonic inspection of steel plate; that the premium for this inspection be reduced substantially; and that suitable methods be developed for reporting the results of such inspections including acceptance levels of cleanliness;
8.23 (ii) and (iii), and 8.24 (i) and (ii)

20. that the pressure vessel fabrication industry indicates its weldability requirements to the steel industry; and conversely asks steelmakers to provide statistical information on actual local composition limits;
8.25 and 8.26

21. that a review of the current methods of steel pricing be sought to remove anomalies between carbon and alloy steels and between balanced and killed steels;
8.29

22. that technical collaboration be increased between individual electrode manufacturers, between these and the steelmakers, and that information available on the high and low temperature properties of weldments be increased;
8.34 and 8.37

On R & D, design and standards

23. that information be sought and distributed on what research would be most appropriate and profitable for execution by academic and other bodies to further the pressure vessel industry, and that support be encouraged for such work by the Science Research Council and other bodies;
9.16 (i) to (iii), 9.21 and 9.44

24. that the dissemination and application of R & D information in the appropriate sectors of industry be improved;
9.32 (i) and 9.45

25. that the issue of design memoranda supplemented by further data sheets covering topics of pressure vessel interest be sponsored;
9.32 (ii)

26. that a collaborative Pressure Vessel Research Committee be formed for the pressure vessel industry, preferably as part of a wider reorganisation;
9.41 (i) and (ii)

27. that UK standards for pressure vessels be provided that are at least no more restrictive than those found acceptable in competing countries;
10.4

28. that the requirements in BS 1515 Part I and Part II that the design stress should not exceed the ultimate tensile strength divided by 2.35 and 2.5 respectively be reconsidered forthwith;
10.9

29. that the requirements for acceptance of non-specified and new steels for use in pressure vessel fabrication be established and published;
10.10

30. that provision be made for appeals for novel pressure vessel designs similar to the 'Code Case' procedure used in the USA;
10.13

31. that design stresses for UK steels be maintained at their present levels notwithstanding the lower minimum property levels ascertained more recently arising from the extensive UK materials testing programme;
10.17

32. that the use of torsion test data in pressure vessel design be introduced as an alternative option to the present use of tension test data;
10.25 (i) and (ii)

33. that the present requirements of BS 1515 with regard to fracture toughness, fatigue and creep be reconsidered;
10.33 (i) to (iii), 10.36 (i) and (ii) and 10.42 (i) to (iii)

34. that a new master Standard for pressure parts be prepared covering design, manufacturing procedures and inspection requirements, and that upon completion of this all existing BS for pressure vessels be withdrawn;
10.44 (i) to (iii) and (v) to (vii)

35. that Government discourages its departments and the public bodies from issuing private specifications and invites other vessel purchasers to do likewise;
10.44 (iv)

36. that the review of technical computer applications to the pressure vessel industry undertaken by the National Computing Centre be continued and be completed as quickly as possible;
10.47 (i) and (ii)

37. that the present statutory requirements for reporting accidents and failures involving pressure vessels and boilers be rationalised;
14.5

38. that a critical review be undertaken of pressure vessel failure experience covering failures and major defects occuring either before or during service, so as to recommend appropriate changes in pressure vessel standards where necessary;
14.10

On institutional innovations

39. that in order to reduce difficulties arising from multiplicity of inspection organisations, an 'umbrella' inspection body be set up to approve inspection organisations and inspection services of fabricators, and to authorise the use of a common symbol stamp of approval;
11.24 (i) to (iv) and (vii) to (ix)

40. that in the interests of the maintenance of common standards individual inspectors be certified and that training and retraining facilities be arranged;
11.24 (v) and (vi)

41. that the present variety of BSI Committees relating to pressure vessel standards be replaced by a single new body responsible for the preparation of all standards for pressure vessels, including provision for 'Code Case' appeals, tentative specifications, and the regular review of approved standards;
12.16 (i) to (iii), 12.19 (i) to (iv) and 12.24 (i) and (ii)

42. that a new body—the Pressure Vessel Authority—be created to supervise the preparation and modification of pressure vessel standards (see 41 above), the approval and register of fabricators and inspection organisations (see 12 and 39 above), the collaboration of research and development and the application of its results (see 26 above), the certification of individual inspectors (see 40 above), and other activities relating to pressure vessels.
13.11 (i) and (ii)

It should be noted that the above list contains recommendations with a wide range of levels of information. The items considered by the Committee to be of greatest importance are those summarised in Chapter 15, page 100.

CHAPTER 1

Introduction

General

1.1 During 1965–6, demand in the UK for various types of pressure vessels reached an unprecedentedly high level, with associated difficulties of supply. In this period, various government departments received comment and criticism on a variety of aspects associated with the design and supply of pressure vessels, and this led to the setting up of the Committee of Enquiry on Pressure Vessels in December, 1966. The terms of reference and the subsequent submissions made it clear to the Committee that it must survey a wide range of topics including: the commercial and economic aspects of both demand and supply at home and abroad; the human and organisational problems of labour and management; the structure of the pressure vessel industry and of the associated materials supply, inspection, and specification writing organisations; as well as discussing technical problems of inspection, materials supply, design, and research and development. To collect information and to discuss this breadth of topics in a period of eighteen months has meant it has not been possible for the Committee to make its study as fully detailed as its members would have wished. This has been particularly so on technical aspects. For example, it has not been possible to detail preferred design approaches or a preferred fabrication layout, but only to indicate the general direction of such changes as are considered necessary. The Committee felt that the position of the pressure vessel industry was such that it must present its broad conclusions at an early date so that urgent action could be taken. At the request of the Minister of Technology the Committee has, where possible, indicated the methods whereby recommended actions can be implemented.

1.2 Another difficulty arose from the fact that no unique meaning could be attached to the term 'pressure vessel industry'. In the case of such industries as the aircraft industry, the ship-building industry, and the coal industry, there are real communities of somewhat similar organisations with similar interests. The 'pressure vessel industry', however, is a loosely defined portion of the heavy-fabrication industry and other interests. Many companies of a wide range of sizes and types diversify both into and out of the manufacture of pressure vessels which, in most cases, form only parts of their ranges of products. There is no separate trade association that can speak for the 'pressure vessel industry' as such, and so represent its needs to Government and to the supply industries, nor is there a separate research association or learned institution for the industry.

Definition of pressure vessel

1.3 There is no generally accepted agreement of exactly which engineering structures are defined by the term 'pressure vessel'. It may include structures ranging in size from mammoth nuclear reactor vessels to modest domestic pressure cookers. The range may be extended considerably further to such items as: aeroplane bodies, marine boilers, gas cylinders, transportable gas receivers and high-pressure pipelines amongst others. However, to avoid overlap with other committees and working groups, the Committee decided to exclude these further items from their main study. Also, because of their somewhat specialised requirements, nuclear pressure vessels (both steel and concrete) were excluded, although the Committee looked at all of those items on which information helpful to the more conventional vessels was likely to arise.

1.4 The special importance of 'pressure vessels' arises from experience in the early stages of industrial development of a number of serious accidents involving failure of components containing internal pressure. This led in almost all countries to regulations and safety requirements for boilers containing steam under pressure, and later to similar requirements for unfired pressure containers. The widespread interest common to different categories of pressure vessels arises from the engineering challenge in obtaining the relevant safety precautions with an economy of structure and of materials. This challenge has increased with increasing size and increasing steam pressure of boilers and steam drums in conventional power plant, and with increasing pressure, size and environmental severity in the various pressure vessels used in the chemical, petro-chemical and gas industries. Because of this challenge the Committee has concentrated its discussions on the relatively large vessels used in these industries; such vessels in general are manufactured by welding together shaped metal plate, in most cases steel plate.

1.5 On this basis the Committee defined as a 'pressure vessel' any vessel intended to contain a fluid at a pressure greater than atmospheric pressure which, in general terms, is designed and built according to a pressure vessel code such as BS 1500 or BS 1515 in this country, or ASME Section VIII in the USA, and/or is subjected to inspection requirements. This was taken to include the shells of large heat-exchangers and boilers, but not their internal fittings, pipework or valves. Specifically excluded were nuclear reactor and containment vessels, gas holders for which the pressure did not exceed 70 centimetres water gauge, any pipe or coil, any part of a prime mover, any vessel forming part of a portable tool or any solid drawn gas bottles or cylinders used for the storage and supply of compressed air or compressed and liquified gases. Detailed definitions of the terms used in this report are given in Appendix C. Appendix B gives explanations of the abbreviations and acronyms used in this report. It should also be noted that, except where specifically stated otherwise, the monetary unit is the pound sterling prior to the devaluation of 18th November, 1967, since most of the statistical and trade data originated before that date.

Importance of the industry

1.6 The value of shop-built pressure vessels (including similar heat-exchanger structures and tanks) produced by UK pressure vessel fabricators in 1966 was about £58M. This compares with a total for the same year of about £135M for all heavy shop fabrications by pressure vessel fabricators, and of a total expenditure in 1966 on plant, hardware and equipment (including direct exports and contractors exports, but excluding pipelines) of about £500M. The pressure vessel industry thus represents an important fraction of the heavy fabrication interests of this country. In terms of personnel, the heavy fabrication shops of UK pressure vessel fabricators make use of some 25 000 employees of all types, but not including those employed by manufacturers of materials and equipment used for fabrication of pressure vessels and ancillaries. It may be noted here that, in respect of the economic survey questionnaire returns *only*, their heavy fabrication shops employed 20 000 workers for a heavy fabrication shop output of £113M, giving the heavy fabrication shop average output per man in 1966 as £5600.

1.7 The qualitative importance of the pressure vessel industry is considerably greater than its quantitative position implies. This is due to the safety and legislative implications which have resulted in the pressure vessel industry acquiring highly developed skills in design, manufacture and inspection methods. It therefore represents an important activity in this country which depends so much on its technological ability. The development of these skills has a beneficial influence on other engineering industries. It has particular relevance to the effectiveness of the chemical, petro-chemical and petroleum industries, all of which will continue to play their prominent role in future UK development. Indeed a viable and highly developed pressure vessel industry appears to be regarded internationally as an index of a country's heavy engineering potential. The Committee agrees with this view and considers it in the national interest that all practical steps be taken to ensure that the UK pressure vessel industry is as good as or better than equivalent industries abroad. The Committee also considers that such steps are likely to give good value for money, since it should be possible to influence large areas of engineering activity at relatively small cost. In view of the importance of the pressure vessel industry as part of the general engineering activity of this country, the Government should consider as a matter of urgency all the proposals to improve the industry on lines as suggested throughout this report.

CHAPTER 2

Factors affecting the technology and manufacture of pressure vessels

2.1 The stages in the production of a pressure vessel are: its conceptual design (involving the plant designer or user), detailed design and stress analysis, selection and procurement of materials and welding consumables, inspection and shaping of these materials, fabrication or part-fabrication in welding shops, further inspection and (probably) thermal treatment, transport to site and, in some cases, further fabrication at the site. After various commissioning test procedures the vessel will be put into operation, and throughout its life will be subject to operational controls and periodic inspection. Each of these stages has its effect on the industry as a whole, although this report does not give detailed attention to operational and periodic inspection of vessels.

2.2 Some idea of the relative economic importance of the different aspects can be obtained from the breakdown of tenders offered in 1966 by several UK fabricators for four different high-quality mild steel pressure vessels (Annex A of Appendix F). The average values for all of these indicate about 40–45% of the cost goes on materials including consumables, with some 10% on direct labour, 25–30% on overheads including indirect labour on design and inspection, about 15% on transport and site work, with less than 5% for profit and contingency. This illustration is considered to be typical of pressure vessel cost make-up and this low profit margin is supported by the published trading results of UK fabricators over recent years; on occasion even lower tenders have been offered in an attempt to maintain the work load (see paragraph 5.6).

2.3 The division of costs given in paragraph 2.2 are considered by the Committee to be reasonably typical and it emphasizes the importance of the cost of materials. A change in the price of steel plate will have a major and immediate effect on the cost of a pressure vessel and can influence greatly its export competitiveness. Economy in material resulting from improved design codes and techniques can also lead to substantial economies. The next highest fraction of the costs is that of 'overheads', which depend to a large extent on the organisation and capital equipment of the industry and on the layout and planning of the individual workshops. This aspect also includes the cost of inspection, so that more efficient organisation of inspection arrangements could result directly in reduced overheads. Such changes could lead indirectly to further reductions in overheads if they reduced delays, and thus the time a vessel occupied factory space without being worked on. This aspect of delay is also important in shortening times to delivery and in making offered delivery dates more dependable, factors which have great influence on the choice of supplier by the purchaser of pressure vessels.

2.4 These considerations indicate the importance of the structure and efficiency of the industry in relation to: the demands of possible users, the material supply, the organisation of inspection services, the research on the development towards more economical designs, together with methods for ensuring that design standards are modified promptly to take account of developments in design and manufacture. Recommendations on each of these aspects are made in subsequent chapters.

CHAPTER 3

The structure of the UK pressure vessel industry

Sources of information

3.1 Very little published information existed in 1966 on the supply and demand aspects of the pressure vessel industry to help the Committee in its task. The Process Plant Working Party of NEDC has since 1966 provided estimates of plant demand expenditures but these have not included specific information in respect of pressure vessels. The Committee took two actions to remedy this. It initiated a detailed economic survey conducted by a not-for-profit research institute with the assistance of some members of Ministry of Technology staff, all under the direction of the Economic Survey Steering Group. It suggested that Pressure Vessels should be regarded as separate items from the point of view of obtaining statistical information on imports and exports (see Appendix G). The Customs and Excise import and export statistics had been improved as from the beginning of 1968 by the inclusion of new statistical headings to cover heat exchangers, process pressure vessels for mineral oil refining, and process pressure vessels for other purposes.

3.2 The information on the present structure arises in the main from the economic survey, including nearly 1000 replies to questionnaires, of which over 260 replies provided information from fabricators (producing over 80% of the total estimated UK output of shop-built vessels by pressure vessel fabricators). In addition 34 interviews were conducted with fabricators. More detailed information is given in Appendix F (Chapters 2 and 3).

Output and capacity

3.3 The total output by UK pressure vessel fabricators in 1966 of shop-built pressure vessels, heat exchangers and tanks is estimated to be £58M. Of this about £35M refers to actual pressure vessels, the remainder to analogous tanks and shell heat-exchangers. In addition there was about £16M of site-completed pressure vessels and tanks produced in the same year by UK pressure vessel fabricators (see Appendix F, Chapter 2).

3.4 Because pressure vessel fabrication requires facilities similar to those used in other forms of heavy fabrication, it is difficult to estimate the real UK capacity for pressure vessel construction. The economic survey indicated that the total possible UK output of shop-built heavy fabrications by pressure vessel fabricators in 1966 was £135M, but it is unrealistic to expect all of this to be available for pressure vessel manufacture. A better indication of available capacity may be obtained by considering that all extra heavy fabrication capacity could be devoted to pressure vessels. This available extra capacity in 1966 corresponded to about £11M of product per annum, indicating a possible UK capacity for shop-built pressure vessels, heat exchangers and tanks of about £70M, together with facilities for £16M of site-built pressure vessels and tanks. It should be noted that the spare capacity would not be that best fitted for the production of the more sophisticated types of pressure vessel. In all regions in the UK further spare capacity could result from increased shift-working, provided the availability of labour made this possible.

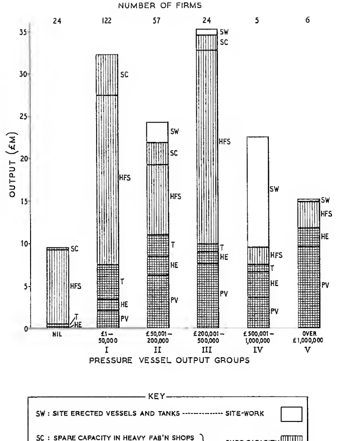

Fig. 1. Output and capacity of the UK pressure vessel industry in 1966 (as returned on questionnaires, analysed by shop-built pressure vessel output groups)

Types of companies

3.5 The general impression of the pressure vessel industry is that of a wide variety of companies, some long established in pressure vessel fabrication, some long established as heavy fabricators but only recently entering the pressure vessel field, and a few who have entered the market in recent years with specially-built fabrication facilities. Whilst diversification with other heavy fabrication activities occurs both into and out of pressure vessel construction, the industry does not itself normally undertake, nor is it associated organisationally with, chemical engineering interests for which so much of its production is earmarked. Inter-company links between fabricators and contractors, and between fabricators and steel producers, are few and small.

3.6 Figure 1 gives a summary of the output of pressure vessels, heat exchangers and tanks in the UK in 1966, broken down in terms of the outputs produced by companies in discrete ranges of pressure vessel output. Whilst the production of pressure vessels continues throughout the UK alongside other types of heavy fabrication, it is found that, in terms of value of pressure vessels produced, the non-specialist pressure vessel producers do not account for a large fraction of the product. The companies for which pressure vessels represented 10% or less of the output of their heavy fabrication shops accounted for only about 7% of the total UK production of shop-built pressure vessels in 1966.

3.7 At the other end of the scale, about 45% of the total output of shop-built pressure vessels in 1966 was produced by the 11 companies in the two survey groups consisting of companies each of which produced pressure vessels totalling more than £½M per annum. It will be seen from Table 3(2) in Appendix F that these companies: have all devoted a considerable fraction of their output to pressure vessels; have mostly been in existence since before 1945; and have shown increases in production which they expected to continue. These factors have considerable implications on the age and layout of their fabrication shops.

3.8 However, it is important to emphasise that 55% of the shop-built pressure vessel production in 1966 came from more than 200 companies each only producing less than £½M worth of pressure vessels per annum, and of this about 30% of the total annual production came from some 180 companies each producing less than £0·2M of pressure vessels each per annum. Moreover these 180 companies appear to be small overall and not merely small producers of pressure vessels; they have an average number of less than 80 men in total in their heavy fabrication shops, and their average annual output of all heavy fabrications is less than £½M.

3.9 An important conclusion from the economic survey is that satisfaction with the profitability of pressure vessel production, as expressed by the fabricators, decreased with increasing size of company (Table 3(2) of Appendix F) even though the output per man in the heavy fabrication shop increased markedly with increase in size of company. The 'output per man' is defined as 'gross sales output per heavy fabrication shop worker'. The questionnaire returns imply: that there is higher productivity in the larger companies; that pressure vessels represent the most costly types of heavy fabrication; and that the larger companies do a larger percentage of the work involving more sophisticated designs and more sophisticated materials. It caused considerable concern to the Committee that it was the larger companies, on which one relied for forward developments, which were the most dissatisfied with the profitability of the business (as expressed subjectively by the fabricators themselves).

Types of product

3.10 Of the companies for which pressure vessel production was a significant activity, about 11 companies offered cranage facilities for, and 15 companies could build, vessels weighing over 100 tons. Furthermore, 10 companies could deal with plate thicknesses over 4 in.; while 6 companies specialised in sitework. These were not necessarily all the same companies. About 25 companies specialised in vessels made from particular materials (e.g. stainless steel or aluminium alloys) or in particular types of vessel (e.g. road tankers). In spite of the higher technological input into these categories, the companies involved showed no higher satisfaction with their profitability than the remaining 180 or so companies offering fabrications primarily of mild steel between $\frac{3}{8}$ in. to 4 in. in thickness or weighing up to 50 tons.

Regional distribution

3.11 The regional distribution of pressure vessel production is summarised in Table 1.

TABLE 1. Estimated regional distribution of UK shop-built pressure vessel output, 1966

	1966 output		Fabrication shops	
	£M	%	Number	%
Scotland	3·8	11	33	11
Northern	3·6	10	25	8
North West	3·3	9	46	15
Yorkshire and Humberside	5·1	15	47	15
East Midlands	2·8	8	25	8
West Midlands	6·6	19	44	14
Wales	0·2	1	6	2
East Anglia	0·5	1	4	1
South East	8·7	25	69	22
South West	0·3	1	10	3
Northern Ireland	*	*	1	<1
Total for UK	34·9	100	310	100

* Denotes negligible output as the shop is not yet in full production

Trade associations

3.12 There is no single trade association for the pressure vessel industry, but the Tank and Industrial Plant Association numbers 84 fabricators capable of producing pressure vessels, although nearly half of these regard their pressure vessel activities as secondary. TIPA does not include all pressure vessel manufacturers, thus of the 50 pressure vessel fabricators currently on the Lloyds Class I list some 21 are not TIPA members. There are some important specialists in stainless steel vessels who also are not members.

3.13 Two other trade associations (British Chemical Plant Manufacturers Association and Council of British Manufacturers of Petroleum Equipment) also include pressure vessels in their terms of reference, and there are several companies who belong to more than one of these associations. There is also a considerable pressure vessel content in the work of the Water-Tube Boiler Makers' Association. The Committee considers that the pressure vessel industry has suffered from the absence of a single trade body to look after its interests.

We therefore recommend that:

(i) there should be a single body to represent the interests of pressure vessel fabricators;

(ii) an appropriate organisation for provision of this single body would be TIPA; (in this case TIPA should be invited to form a division dealing with the special interests of the pressure vessel industry);

(iii) all pressure vessel fabricators be informed that it is in their interests to join TIPA and to support the above division;

(iv) this division of TIPA be recognised officially as the contact and source of information and of representation whenever the collective views of the pressure vessel industry are sought;

(v) this division be organised so that it may provide the additional services referred to in paragraphs 5.19, and 6.3 to 6.4.

Comparison with foreign pressure vessel industries

3.14 The economic survey included a study of pressure vessel industries in the major competing countries, i.e. those of Western Europe and Japan. Detailed results are given in Appendix F, and the main approximate statistics are summarised in Table 2. In terms of 1966 output, the UK pressure vessel industry is one of the largest, being slightly exceeded by the Federal Republic of Germany, but slightly in excess of that in Japan (all the figures in the Table should be taken as approximate only). Italy, whose pressure vessel industry has recently provided active competition in the UK, has an industry less than a third the UK size, and its output during the 1964–6 period has decreased in contrast to the marked increase in UK output over a similar period.

3.15 The country which shows the biggest difference from the UK in the structure of the pressure vessel industry is Japan, where over half the annual production comes from only nine (or even fewer) companies each producing on

TABLE 2. International comparison of pressure vessel industries for 1966

(Approximate Data Only)

	STRUCTURE OF INDUSTRY				DEMAND		EXPORT/IMPORT TRADE				
	(a) Total output	(b) No. of companies estimated as making half output in (a)	(c)= a/2b Annual output of average company in column (b)	(d) *Annual* % increase in output	(e) *Annual* % increase in equipment investment	(f) Estimate of *annual* % increase in domestic demand	(g) Gross exports (approximate)	(h)= 100g/a Gross exports as % of output	(i) Gross Imports (approximate)	(j)= (g–i) Nett trade balance (approximate)	(k) *Annual* % increase in exports
Data for period:	1966	1966	1966	1964–66	1964–66	1966–72	1966	1966	1966	1966	1964–66
Units:(1)	£M	No.	£M	%	%	%	£M	%	£M	£M	%
F.R. Germany	70	15—20	1·7—2·3	+8	+12	+8	17	24	1·7	+15	+8
Japan	60±5	4—9	3·8—8·1	+1	+13	12	20	30	0	+20	+100
United Kingdom	66(1)	21	1·5	+30(2)	+20(3)	—4(3)	8	16	9·5	−1·5	0(6)
France	40	10—15	1·3—2·0	+3	+12	+5	—	—	—	—(5)	—
Italy	18	5—10	0·9—1·8	−9	+4(4)	+5	3—5	17—32	0·7	+2·3—4·8	+40
Sweden	4	1—2	1—2	+2	+20	—	0·3	9	0·2	+0·1	−27

NOTES:
1. £M for all countries is in pre-devaluation £ (i.e. $2·80 to the £1). All data refer to pressure vessels, heat exchangers and tanks. In data for foreign countries it was not possible to distinguish between shop-built and site-built output, and a proportion of site-built output probably comes within the total output figures. To enable a reasonable comparison to be made the UK output data in column (a) of £66M has been obtained by adding all shop output (£58M) to half of site output (£16M).
2. Based on orders received by 18 companies representing 30% of pressure vessel output; this result is not statistically significant but it is believed to be reasonably representative of the trend during 1964–6.
3. UK demand estimates based on the four major sectors: chemicals, gas, oil refining, and electricity generation.
4. For 1963–4 the figure is —15%.
5. France is a nett exporter of heat exchangers (£5M were exported from a total production of £10M in 1966).
6. This figure is for direct exports during 1964–6 (i.e. not via contractors); in contrast the direct exports during 1962–4 doubled in value.

(d), (e), (k)—These columns are based on smoothed curves wherever a historic series of data exists.

average over £4M output annually. The average 1966 output for the UK companies providing half the annual production is only about £1·5M, whilst in the Federal Republic of Germany the figure is about £2M. The general picture of a somewhat larger number of smaller companies in the UK is thus affirmed. However, in all countries (except Japan) there do exist considerable numbers of less specialised fabricators undertaking pressure vessel business.

3.16 A major difference between the leading UK pressure vessel fabricators and their counterparts in other countries is the degree of integration found in the industries abroad. In the Federal Republic of Germany, in Japan and in Sweden there is a high degree of integration with the steel producing industry, and whilst this is less so in France and Italy, it is still significant compared with the virtual lack of integration in the UK. The form of integration varies from one of finance only, to the siting of large steel production units and fabrication facilities alongside each other. Such links can be used to give flexibility in pricing and can be beneficial through the better technical understanding by the steelmakers of the demands of the fabrication industry. The economic survey reported few criticisms of material supply abroad, in contrast with experience in the UK. In Japan there is also a high level of integration with the chemical and petro-chemical industries as well as with engineering contractors through which pressure vessels can be sold as part of a whole process plant. This latter form of integration also exists to a lesser extent in some European countries. The importance of such contractors in relation to the demand for pressure vessels is stressed in Chapter 4. Another practice common in countries abroad but not used frequently in the UK is that of the formation of *ad-hoc* groups of companies. These groups would essentially be *ad-hoc* and exist for the duration of a particular project. The groups would involve fabricators and contractors with an entrepreneur, with whom they would share the risk.

CHAPTER 4

The demand for pressure vessels

Sources of information

4.1 This chapter is based on the economic survey, which comprises the report of the consultants augmented with further analysis by Ministry of Technology staff including supplementary information. In addition to published data from various sources, the economic survey team received information from the UK chemical engineering contractors, the Gas Council and the oil companies, and from a special sample survey made by the Chemical Industries Association. The information is summarised in Appendix F, Chapters 5 and 6.

The structure of the demand

4.2 About 60%—70% of pressure vessels procured in the four main demand sectors in the UK are bought by contractors (including the contracting divisions of major plant users) for installation in complete plants. There are about 20 such contractors or contracting divisions in the UK (of which six are members of the British Chemical Engineering Contractors' Association), and these have been the most significant exporters of capital plant through overseas turnkey plant orders. It is expected that in future years the role of the chemical engineering contractor will increase. The main exception has been the Central Electricity Generating Board, for which pressure vessels have been fabricated or bought in by the company or group assuming responsibility for their design and installation. There are other pressure vessels not passing through contractors that are for replacement and modification or for small plant. Many of the vessels bought directly for small plant are manufactured from stainless steel.

4.3 The main final-demand sectors have been various branches of the chemical industry (especially heavy organics, fertilisers, inorganics and dyestuffs), mineral oil refining, the town gas industry and electrical power generation. These requirements are summarised qualitatively in Table 3, but a considerable amount of detailed information was provided in the various submissions to the Committee. The value of this information could be increased by technical assessments of demand sectors in terms of the types of pressure vessel likely to be required in the future (see Appendix F, Chapter 19).

We therefore recommend that

> the Ministry of Technology encourages the initiation of a technical assessment of future pressure vessel demand as outlined in Appendix F, (Chapter 19).

4.4 The level of purchases of pressure vessels, heat exchangers and tanks in four major demand sectors in 1965 and 1966 were:

	1965	*1966*
Gas	£3·9M	£6·6M
Electricity	£7·0M	£7·7M
Mineral Oil Refining ..	£3·8—5·5M	£6·9—9·9M
Chemical Industry ..	£13·4—16·5M	£20·6—23·5M
TOTALS	£28·1—32·9M	£41·8—47·7M

TABLE 3. Qualitative analysis of likely trends

INDUSTRIAL SECTORS		PRIMARY								SECONDARY									OTHER				
TYPES OF VESSELS		Mineral Oil Refining	Town Gas	Electricity Generation	Heavy Organic Chemicals	Fertilizers and Pesticides	Inorganic Chemicals	Dyestuffs	Industrial Gases	Fine Chem, Pharmaceuticals, Toilet Prep.	Coke Ovens and Coal Tar Products	Synthetic Resins and Plastics	Vegetable and Animal Oils and Fats	Sugar Refining	Food and Drink NES	Pulp and Paper	Cement	Transport	Brewing	Synthetic Rubber	Polishes	Gelatine and Adhesives	Soap and Detergents
TANKS	Tanks, plate small, erected on site	ps	pd		ps	os	os				os		os	os	os					os		os	os
	Tanks, shop built		od			os	os	os		os	os	os	os	os	ps	ps	ps	pg	ps	os	ps	pg	ps
PRESSURE VESSELS AND HEAT EXCHANGERS	Carbon and low alloy steel	pls phg	old pdh	pld phs	pls phg	pls	pls ohs	pld ohd		pld	pls ohs	pls	pls	pls	pls			plg	pld	pls ohg	pls	pld	olg
	High alloy steel inc. high tensile	ohg	pdh	plg		olg	olg																
	Stainless and nickel alloys incl. clad.	olg ohg	old ohd	ols	pls phg	plg ohg	olg oh	plg ohg	plg phg	pls	olg	ols	olg	plg	plg			olg	olg	ols ohg	pls		olg
	Aluminium and its alloys						ols		pls									olg					
	Glass, reactive metal and solid resin clad	olg						plg		ols		ols							pld	pls ohg			
	Spheres	ohg	ohg						olg														
	Pressure vessel trends	hg	hd	ls	hg	hg lg	ls	ls hs	hg	ls	ls	ls	ls	ls	ls	ls	ls	ls	lg	ls	ls	ls	ls

Source: Interview programme. Symbols: p=principal. o=occasional and secondary. l=low pressure (less than 300 psig). h=high pressure (more than 300 psig.) g=use growing in plant. s=use static in plant. d=use declining in plant.

Variation of demand in the four main sectors

4.5 An important feature showed by the demand analysis is that the UK pressure vessel, heat exchanger and tank procurement for the four sectors increased from about £19M in 1962 to about £45M in 1966. This is reflected in pressure vessel orders placed on 18 fabricators, which doubled over the two years from 1963 to 1965 (see Fig. 3(12) of Appendix F). Similar conclusions can be drawn from the figures for the output by value of pressure vessel ends (see Fig. 1 of Appendix H) which increased by a factor of 2·5 between 1963 and 1966. This increased output occurred in all pressure vessel output groups, and did not arise from an increased fraction of the work going to non-specialist fabricators.

4.6 It may be recalled that many of the complaints of short-comings in the pressure vessel industry arose from experiences during this period of high demand. Perhaps the surprising feature is not that the industry failed to satisfy all of its customers, but that it was able to make this very creditable increase in output and that imports did not increase more markedly.

4.7 Unfortunately, after this peak in 1966, the demand fell again almost as rapidly so that the problems facing the industry in 1967–8 were very different from those existing at the time the Committee of Enquiry was formed. An example of the cut-back in demand is afforded by Table 6(29) of Appendix F, in which demand in all chemical sub-sectors except heavy organics fell to negligible levels. By June, 1967 this trend towards decreasing demand, with its implications of short-time working and the laying-off of labour, was so marked that the Committee, in the absence of a single trade association specifically covering the pressure vessel industry, felt it necessary to draw the magnitude of the decrease to the attention of the Ministry of Technology. A major fear was that, as had previously happened, skilled men once lost to the industry would not return and the industry would be weakened permanently. A delegation from the Committee saw the Joint Parliamentary Secretary Mr. E. Dell on 20th July, 1967, who accepted the evidence for this down turn, and discussed methods to alleviate the situation (see Appendix H). However, the position continued to worsen throughout 1967 and this was emphasised at another special meeting held on 16th October, 1967, with Dr. J. Bray, who had then become the Joint Parliamentary Secretary covering, *interalia*, the process plant industry.

4.8 The Committee considers these very large fluctuations in demand have detrimental effects on the industry, both with respect to plant, equipment and techniques for providing an efficient service, and with respect to the continued availability of sufficient skilled labour. Some alleviation of this cyclical behaviour could result from action by fabricators and by their customers. For example, the fabricators could ensure more flexibility in production by increasing the flexibility of both equipment and of labour. They should be encouraged to anticipate changes in the volume and type of demand for pressure vessels by sponsoring market research. They should also stimulate demand by increased salesmanship, involving the use of engineering representatives and closer liaison with contractors. Nevertheless, the fluctuations in demand albeit greater in magnitude largely reflected the economic pattern of the country as a whole, and was thus amenable to Government action. The Committee considers that special attention should be given to remedying the fluctuations in demand placed on the pressure vessel industry, because of the importance of this industry on the country's overall engineering activity.

We therefore recommend that

> the Government be asked to consider what steps can be taken to reduce the magnitude of fluctuations in demand placed on the pressure vessel industry. (Possible measures include: control in the timing of placing of orders within the public sector; consideration of the requirements of public sector bodies, so as to identify standard units that could be ordered for stock at times of low activity; and provision of special loans to cover such stock piling. The authorisation of small amounts of money for design, during periods when investment was curtailed, could accelerate the subsequent upturn of work.)

Prediction of future demand

4.9 The demand increased progressively through the period 1962 to 1966, and this was associated with massive and abnormal investment in the four main demand sectors: mineral oil refining (refining capacity nearly doubled during this period); gas production industry (associated with plant for producing gas from oil); electricity generation; and the major chemical industries. Much of this upswing in investment had passed by 1967–8. The gas industry turned its investment from pressure vessels for gas manufacture towards equipment for the distribution of natural gas. The other industries had expanded sufficiently to meet the domestic demand for several years to come. These changes, together with general changes in the economic climate, had already been reflected in the shortage of orders in 1967–8 noted in paragraph 4.7.

4.10 Estimates of future pressure vessel demand for the four main demand sectors were made as part of the economic survey (see Appendix F, Chapter 6). Demand trend figures, ignoring cyclic or other fluctuations, were estimated as follows:

	1972	*1977*
Gas	£2·1M	£1–2M
Electricity	£5·2M	£6·1–9·5M
Oil Refining	£2·6–3·7M	£3·3–4·7M
Chemical Industry ..	£19·7–29·6M	£25·2–37·8M
TOTALS	£29·6–40·6M	£35·6–54·0M

The figure for electricity generation is based on the assumption that, in spite of the fall in demand for boiler drums for conventional electricity generation, there will be a demand for structures similar to pressure vessels for nuclear plant.

4.11 After careful consideration the Committee supports these estimates, which indicate that the UK vessel demand would fall from the peak reached in 1966, the demand in 1972 being only slightly greater than that recorded for 1965 (see paragraphs 4.4 and 4.10). Further, the estimates indicate that UK pressure vessel demand may not grow much over the period 1966 to 1977, the demand in 1977 being only about that for the peak year 1966. There is thus no indication of a need for much greater capacity for fabricating vessels for home demand even 10 years hence. The above comments of course relate only to quantity, and there could be increasing demands for vessels of greater sophistication requiring changes in the existing industry. One purpose of the techno-economic assessment proposal suggested in paragraph 4.3 is to determine the need for such changes.

CHAPTER 5

Imports and exports

The 1966 pressure vessel trade balance

5.1 The shop and site-built vessel output by UK pressure vessel fabricators in 1966 is estimated, within reasonably close limits, as £74M (see paragraph 3.3). No representative data could be obtained (as at 1967) of the level of imports or of exports of vessels in 1966. The situation in respect of availability of import/export information for vessels has markedly improved as from January 1968 (see paragraph 3.1). Estimates made by the economic survey team lead to the suggestion that in 1966 total vessel imports were about £9·5M and vessel exports were about £8M, implying a negative trade gap of about £1·5M. However, since this figure for the trade gap is within the range of estimating errors, too much attention should not be paid towards this figure.

5.2 Whilst the estimated level of imports in 1966 is not at first sight surprising in view of the large increase in demand, nevertheless there was at the time heavy fabrication capacity available (see Fig. 1), and some explanation is needed. There were only a few cases where vessels were imported because it was not technically possible to manufacture them in this country. The main reasons for imports were believed to be the two traditional commercial factors of the cost and the time required for delivery.

Comparative prices

5.3 It is difficult to make a quantitative assessment of representative differences in costs from one country to another. For a given pressure vessel the tenders received vary greatly from one company to another even in the same country, and the position varies markedly with time and with the nature of the product. The examples quoted in Appendix F (Annex F) serve to emphasise these points, as do the various examples given in evidence to the Committee. The generalisations in the following paragraphs are based on these, but individual examples show considerable variation.

5.4 The UK pressure vessel industry was heavily loaded during the later part of 1965 and much of 1966. A series of quotations for 42 vessels of various types at this time showed a total price (as delivered) of £310 000 from UK fabricators, against £288 100 from Japan, £230 000 from Germany and £218 000 from Italy. Throughout this period a large number of tender quotations from Italy were considerably lower than (in some cases only half of) the UK prices. Since 1966 the UK pressure vessel industry has become more competitive, and this is considered in some detail in the ensuing paragraphs.

5.5 The low Italian prices in 1965–6 cannot be explained in terms of wages, since with inclusion of social costs their average wage and social costs were about 88% of the UK costs. The normal cost of steel in Italy is roughly the same as that in the UK and, although Italian pressure vessels built for export receive a steel subsidy of about 5%, the lower quotations represented pressure vessel prices amounting to little more than the cost of the steel. Further export rebates (for example, reimbursed taxes) can amount to 10–15% (see Appendix F, Chapter 12) enabling a price advantage of 13–20% for export orders. However, the exceptionally low prices for selected vessels in 1966 reflected the determination of the Italian pressure vessel industry to find work in spite of a big drop in Italian domestic demand over the period 1963 to 1965 (see Appendix F, Chapter 12). To keep their skilled labour force active, Italian fabricators were prepared to sell at a price lower than the true average cost price; whether this involved the companies concerned in direct loss, or whether some subsidy was given could not be ascertained, nor is it of real importance except that it effects the length of time that their industry could afford to continue such a policy. Whilst the Committee believes that during this period, the sale of some Italian pressure vessels in the UK amounted to 'dumping' as defined in Appendix F (Chapter 12), it cannot produce the level of proof necessary for diplomatic action. Since this is always likely to be the case, other preventive measures are needed.

We therefore recommend that

(i) the British Government be prepared to act quickly and informally with other Governments when 'dumping' is suspected even if the evidence is insufficient for formal action;

(ii) the Government maintains close contact with contractors to obtain any information which would indicate and provide evidence of occasions when artificially low prices were being offered;

(iii) the Government discourages the use of UK finance for purchases from abroad under such circumstances.

5.6 The relative pricing position began to change in 1967 following on a shortage of orders in the UK industry. For example, quotations for a mild steel vessel in March 1967 showed a UK lowest price of £7800 against a Federal Republic of Germany lowest of £6500 and Italian lowest of £6950, with Dutch and US prices considerably higher. By September 1967, the lowest UK quotation for exactly similar vessels was only £4910 against the lowest German quotation of £6100. This later UK quotation must have been well below cost in an attempt to maintain employment. The average of the prices offered by the UK companies was almost identical with the average of the prices offered by the German companies (£6500).

5.7 The UK pressure vessel industry must not, however, be complacent about its price levels. Very low quotations at times of shortage of orders similar to that mentioned in paragraph 5.6 must involve a sizeable loss; even under normal circumstances the industry complains of low profit margin. The average profit and contingency applied to the quotations given in Appendix F (Annex A) was less than 5%. In most cases, the UK pressure vessel industry appears to be able (at the prices prevailing before the 1967 devaluation) to match the price of foreign vessels imported into the UK, but it must be remembered that there is an import tariff barrier of 14–15% in addition to any transport costs. British contractors expressed the view that UK pressure vessels would in general be more expensive than foreign vessels on sites outside this country, even where the UK vessels did not face a barrier such as the 10% tariff applied by Common Market countries. The recent sterling devaluation of 14% will help, but this may only result in a reduction of prices by around 5%, due to loss of the previous export rebate and to increases in some of the manufacturing costs. It is very necessary to look for ways of further reducing UK prices, which emphasises the importance of the measures for increasing efficiency proposed in the ensuing chapters.

Delivery period

5.8 During the period of exceptionally high UK demand in 1965–6 the UK pressure vessel industry quoted long delivery periods, up to 50% longer than quotations from some Continental companies. This position had altered by 1967 with decreasing demand on the UK industry, and quotations during 1967–8 showed delivery periods comparable with the shortest offered from abroad.

5.9 A more serious complaint frequently made by purchasers was that UK fabricators failed to meet their offered delivery dates. One example (see Annex F of Appendix F) showed that of 75 vessels for delivery in 1965–6, only four were on time and over half (41) were more than three months late. Another example over the same period involved forty-seven orders totalling £290 000. Of these 18 were delivered on time, 15 were up to one month late, 9 were from one to two months late and 5 were over three months late. This criticism applies not only to the UK fabrication industry as delays occurred with orders from abroad, for example during early 1968 with imports from Italy. At the same time the delivery performance by UK fabricators greatly improved in 1968. Clients regard promptness in delivery as very important; the causes of delivery delays are discussed in later chapters and some possible remedies recommended.

Promotion of exports

5.10 The predictions summarised in paragraph 4.10 and 4.11 indicate that UK vessel demand may not grow during the period 1966–77. It is thus neccessary to attempt to increase the UK vessel export trade if full use is to be made of the potential capacity of the heavy fabrication industry. This could also help to reduce the peaks and troughs in demand on the fabrication industry which, in the present situation, reflected the fluctuations in the whole UK economy. Such fluctuations do not necessarily occur in all countries at the same time, so that a wider market could lead to a more constant demand. The possibility of increasing UK pressure vessel exports is emphasised by the very approximate trade balance figures for different countries in 1966 shown in Table 2. Of the six countries listed, only the UK imported more than was exported, while the Federal Republic of Germany, Japan and Italy had nett exports of about £15M, £20M and £4M respectively, representing 20–30% of their annual production in each case.

5.11 To export a similar fraction of the UK pressure vessel production would involve exports to a value almost treble the 1966 figure. Moreover in 1966 very few pressure vessels (about £1·5M) were exported by the direct efforts of fabricators. Of the total exports of about £8M, more than £6·5M were exported through chemical engineering contractors. Experience in other fields indicated that increase of exports would not result simply from being able to provide attractive prices and deliveries. Additionally it will be necessary for UK fabricators to develop a policy of actively seeking export orders.

5.12 The low level of direct exports results largely from the negative and pessimistic attitude of some UK fabricators, few of which have international operations or are 'export minded'. Generally they have not the individual resources to mount the necessary exploration and selling effort; nor have they made collective arrangements with other UK companies; nor have they been able to develop contacts with overseas contractors.

5.13 Another factor is that in all countries (other than the UK) there is a strong tendency to insist on local hardware whenever possible. Moreover, the conventional mild steel pressure vessel does not require a high level of technological development, and such vessels have a low added-value content and incur high transport costs relative to their value. An export-orientated fabrication industry would have to make full use of its technological resources by concentrating on vessels of high added-value which may involve innovation in design or materials. Examples are the production of thick and heavy vessels, the organisation of site fabrication, and the use of alloy steels, clad steels, stainless steels and non-ferrous metals. Which of these aspects are most worthy of development requires market research and technical appraisal of future developments in user industries. In addition to the long term survey proposed in paragraph 4.3, it is suggested that the pressure vessel industry should set up a common organisation to gather market information, especially from abroad. This work is specialised, requiring technical and commercial knowledge and the ability to make contacts in foreign countries. The effort involved would be too much for any one company, but it could be done by asking TIPA to provide a 'Market Information Service'.

5.14 Exports would be facilitated by overseas salesmen, overseas offices and/or agents, but very few companies have these. It may be possible to arrange such facilities for groups of companies, or for 'export companies' formed from groups of companies. An active Export Council could be formed within TIPA to advise and act as a stimulant to such arrangements. Such a Council could also help in dealing with other common export problems. These include the difficulties of planning transport routes at home and abroad, and of actually providing specialised transport by ship, with appropriate harbour facilities for handling heavy pressure vessels where these are not available (see Appendix J).

5.15 Because such a large fraction of pressure vessels are installed by chemical contractors, it is necessary for UK fabricators to develop contacts and 'sell' their products to overseas contractors, who are in almost all countries important intermediaries in pressure vessel procurement (a list of such contractors is given in Annex G of Appendix F). An action that could provide helpful publicity would be for TIPA to prepare a Manual indicating the production range, capacity, special equipment and expertise of each UK company involved in pressure vessel, tank and heat-exchanger fabrication. Particular areas to which increased exports appear possible are the COMECON countries and Latin America (see Appendix F, Chapters 9, 15 and 16).

5.16 The main sources of vessel export would probably continue to arise through supplies to UK contractors who had won overseas orders for complete plant.

Where credit is available the main factors are competitiveness in price and delivery. Nevertheless, in all export areas, an increased understanding of the special requirements of foreign customers would help. Notes on technical help to exporters are produced by BSI, a number of which cover pressure vessels and boilers for particular countries. The extension of these to cover other countries is welcomed, as is their supplementation by full translations of the more important foreign design standards.

5.17 The importance of Government help in increasing the level of exports of a particular industry cannot be overemphasised, especially where exports are to countries where barter agreements or wide-ranging trade treaties are involved. With regard to export credit facilities, these are important in reducing the tie-up of working capital. Whilst the EGCD provides a good service within its terms of reference, it suffers from inflexibility and is less readily available to the smaller companies. The Committee considers that a limiting factor on the export of pressure vessels is the provision of export credit guarantees, and the Government should consider means of improving the position (see Appendix K).

5.18 It is also important to ensure that inspection arrangements are available in the UK which are accepted by the country of destination. This aspect is discussed further in Chapter 11, but it should be noted that at times in parts of the USA and in Germany, the requirements of particular inspection organisations have reportedly been used to discourage imports into these countries. The British Government must be quick to act against such artificial barriers, which indicate that other countries are more ready than the UK to apply various measures to favour their domestic industries and to discourage imports.

5.19 If the UK is to maintain a viable heavy-fabrication industry, which is regarded as essential for a technologically highly developed country, then this industry must be given all possible encouragement to change its present attitude and to become export orientated.

We therefore recommend that

(i) a Pressure Vessel Export Council be set up to advise industry on all aspects regarding exports, and to provide overseas facilities for groups of companies as described in paragraph 5.14;

(ii) a 'Manual of Pressure Vessel, Heat Exchanger and Tank Manufacturers' be prepared by TIPA as described in paragraph 5.15, to be circulated to possible customers to inform them of UK facilities;

(iii) TIPA, with assistance from the Ministry of Technology and the Foreign Office, be responsible for initiating a Market Information Service, described in paragraph 5.13;

(iv) the Ministry of Technology encourages the preparation and issue of further notes similar to the technical help to exporters notes referred to in paragraph 5.16 and arranges for circulation of complete translations of the more important standards and statutory requirements;

(v) the Government considers how to improve the Export Credit Guarantee system, and considers the interests of the capital goods industries including pressure vessels when arranging trade treaty or barter agreements; the Government should also be ready to take steps to reduce foreign barriers to imports;

(vi) the Government encourages those companies which become export-orientated by every means possible.

CHAPTER 6

Customer/fabricator relationships

Delivery delays

6.1 Because chemical engineering contractors provide the major outlet for pressure vessels, it is important to take note of their comments on the ways the pressure vessel industry can be improved. These comments are summarised in Appendix F (Chapter 4 and Annex C). Major comments relate to delays and excessive times for fabrication.

6.2 The chemical engineering contractors state that difficulties begin at the quotation stage. British fabricators often ask for additional time to quote, or submit incomplete quotations. Apart from the time lost, these delays can cause contractors to lose plant orders. Fabricators tend to minimise the difficulties and to underestimate the time required to prepare detailed drawings and to obtain approval by contractor, inspection authority or client. This criticism does not apply to all companies, and results in part from the shortage of staff with drafting ability. Similarly, the contractors feel that the fabricators tend to be optimistic about material supply, that they do not order their materials sufficiently in advance, and that they provide insufficient allowances for contingencies. Contractors claim that UK quotations for delivery periods were longer than those from Continental companies, although this was probably a feature of the period of high demand in 1965–6. The delivery situation has improved with decrease in the workload on UK fabricators (see paragraph 4.5–4.8); nevertheless this aspect is so important that the problems and their possible remedies must be considered.

6.3 The most serious criticisms relate to delays in final delivery. The causes of late deliveries were investigated for the forty-seven orders discussed in paragraph 5.9. It was found that about a third of these delays resulted from difficulties in supply of material, a sixth from design modifications and a half from fabricator delays. The problems of material supply are discussed in Chapter 8. With regard to design modifications, it is pointed out that chemical plant is rarely completely designed before construction begins, and about the last item to be fixed is the detailed piping arrangement. Thus the positions and sizes of nozzles are often changed after construction has started. The fabricators suspect that many of the modifications are unnecessary but contractors state that modifications must occur. However, fabricators rarely allow sufficient contingency to cover such modifications, and they are rarely mentioned in contracts. Closer co-operation between fabricators and contractors to obtain a better understanding of each others problems would be very helpful. For example, different types of modification affect the construction period very differently. The sizes of dished ends, of plate thicknesses and of diameters must be fixed early in a contract, but positions of nozzles and of attachments need not be fixed until later, while sizes of these may be varied even later still, except for long delivery items which can often include forged nozzles. The concept of progressive 'freeze dates' for different aspects of the design, agreed at the time of placing the contract, can be beneficial to both fabricator and contractor. It is also important for contractors to emphasise to clients the delays that result from modifications to specifications made by clients. Similarly fabricators should inform contractors promptly of the time and price implications of design modifications, and only accept such changes in writing from an authorised person. This aspect is just one of the many in which the Committee considers that closer co-operation between fabricators and customers would be helpful.

We therefore recommend that

> regular forums be organised (for example by TIPA) at which technical and organisational problems and future demand assessments can be discussed with representatives of the British Chemical Engineering Contractors Association and of other customers.

6.4 The remaining major element in delay is the responsibility of the fabricator. This can arise from the organisation of inspection or from unexpected technical difficulties. In some cases delays arose from swamping of production capacity through the natural inclinations of fabricators to take as many orders as possible during peak periods of demand as a hedge against a feared recession. In many cases however it resulted from poor production control and poor interdepartmental liaison in the fabricators' works. An associated complaint by the contractors was that they had considerable difficulty in obtaining accurate and informative progress statements from many fabricators. Whilst several of the larger fabricators had introduced modern and effective production control procedures and customer progress reports, these were still only satisfactory in a minority of organisations. In particular, poor communications between the sales and production departments of some fabricators had led to unrealistic quotations of delivery dates. Whilst this required remedial action by the fabricators, this could be hastened by responsible approaches by their customers. Customers all too often selected fabricators only on price, encouraging the 'time-to-time' fabricators with low overheads and associated unsophisticated design and control facilities. With regard to action by the fabricators in 1967 TIPA commissioned a consultant to recommend on how to improve the efficiency of its member companies. However, TIPA should not await the outcome of that survey, but should immediately encourage the wider use by its members of modern contractual and production control procedures. The Committee hopes that those members of TIPA who had already adopted modern production control techniques might provide information to other members.

We therefore recommend that

(i) the Government encourages organisations in the public sector to place orders only on fabricators that can produce evidence that they use satisfactory production control and progress statement systems;

(ii) BCECA and other customers' organisations be notified of the above Government action, and be invited to follow a similar policy;

(iii) TIPA be invited to encourage the adoption, by its members, of appropriate production control techniques and of good interdepartmental communications.

Design contribution

6.5 The design of a pressure vessel can be divided into two parts: the functional aspects, and the mechanical details. The functional aspects—operating conditions, overall dimensions and positions of openings—must be defined by the purchaser, but much of the mechanical detail can best be determined by the fabricator. However (except for some of the larger fabricators) the design facilities offered by UK fabricators are limited. Their drawing offices vary from those with about 3 draughtsmen in companies employing about 60 manual workers up to those with 20 or 30 in companies employing about 500 manual workers (see Appendix F Annex C). Up to one in three of the drawing office staff can be regarded as designers. Some purchasers have suggested that companies in the Federal Republic of Germany and Japan were more willing and more capable of providing design assistance and technical advice, especially for the more awkward high pressure vessels. This comment probably results from the much greater concentration of the German and Japanese pressure vessel industries into larger individual fabricating companies than in the UK, though some customers expressed themselves as quite satisfied with the design assistance offered by the larger UK fabricators. It was reported that there are particular difficulties in getting a design contribution from the manufacturers of forged vessels. Whilst fabricators complain that purchasers tend to select a tender on the basis of price alone, and do not make allowance for the degree of technical contribution from the supplier, the purchasers say that fabricators with the technical knowhow do get the bulk of the orders for specialised vessels. This, in turn, leads to improvements in the experience of such fabricators and their ability to be competitive. Since the economic demand analysis makes it clear that the future of the UK pressure vessel industry relies upon its capability of making vessels of higher added value and of advanced design and technology, it is important that fabricators should have the necessary design ability. This is one advantage to be expected from rationalisation of the industry, as well as from such steps as the pooling of computer techniques (see paragraphs 7.21 and 10.46).

Buying and selling procedures

6.6 One obstacle to the fabricators putting more design effort into enquiries (at their early stages) is the very small ratio of the number of contracts won by the fabricators to the number of estimates prepared. Success rates of only 5% are stated to be not uncommon (see Appendix F, Chapter 4). This arises from the number of tenders invited at each stage, since several main contractors, in tendering for a particular plant, may each request several tenders for each pressure vessel subcontract. Many tender enquires are only circulated to obtain approximate costs for budgeting purposes. It is rarely the case for any budgetary enquiry to be so described.

6.7 With some purchasers it appeared that, whilst technical advice was taken as to which fabricators should tender, technical advice played little part subsequently in the final tender assessment. Whilst incentives to purchase at the lowest prices were considerable, it must be recognised by UK chemical engineering contractors that their long term interests rested in support of a technically strong indigenous fabrication industry.

We therefore recommend that

(i) the public sector takes steps to reduce the number of enquiries per tender which ultimately go out to fabricators;

(ii) representatives of BCECA, TIPA and other parties discuss how best to modify their purchasing/selling procedures to save time and money by decreasing the number of unsuccessful tenders prepared for any given job;

(iii) all parties be invited to identify any costing or budgeting enquiries as such.

6.8 Fabricators should be more selective about which tender enquiries they accepted for detailed estimating work. Fabricators should also inform prospective customers of those production sectors in which they have special skills or facilities. The measures discussed in paragraphs 5.13 – 5.15 with respect to exports are also relevant to home sales.

Other aspects

6.9 During the fall-back of vessel demand in 1967 there was considerable bitterness in the attitude of many of the fabricators arising from this fall-back and subsequent shortage of work, following so closely on their attempts to meet the severe criticisms of inadequate output during the earlier period of high demand during 1966. This emphasises the need for frequent exchanges between representatives of the purchasers and of the fabricators. These exchanges should be undertaken not only at senior level. Visits by the more junior contractors' staff to the fabricators works, as has been offered by some fabricators, should be encouraged. These exchanges would help to reduce complaints in the future, for example through the requirements of a contract not being sufficiently well defined leading to discrepancies and to increased costs. Demands for inspection or fabrication procedures, which do not form part of accepted practice and are not specified explicitly at the contract stage, are real sources of grievance and can lead to significant delays. On the other hand, fabricators are accused of submitting low bids, and of then delaying the work to discuss user requirements omitted in the user specifications. Such a situation reflects on lack of technical appreciation of tenders by the purchasers (paragraph 6.7).

CHAPTER 7

Fabrication plant, personnel and organisation

Equipment

7.1 A detailed analysis of the equipment available in certain UK heavy fabrication shops, based upon 27 companies (each with shop output of pressure vessels in 1966 of £0·2M or more) replying to the pilot and long questionnaires, is given in Appendix F (Annex B). A less detailed analysis of the questionnaire returns from over 200 fabricators is given in Appendix F (Chapter 3). For a detailed presentation of data on equipment the reader is referred to these.

7.2 The general impression gained from the questionnaire returns and the supporting visits was that the *specialist* UK pressure vessel fabricators have equipment that is about as good as that of foreign competitors. Most UK fabricators individually want to invest in new equipment but find difficulty in justifying capital investment against the low level of expected returns. The large companies, including the specialist pressure vessel fabricators, have been more ready to invest capital against a long-term hope rather than a short-term justification. Unfortunately much of the modern and specialised equipment is not fully utilised, a situation which will only be remedied by rationalisation of the industry with sharing and centralisation of particular facilities.

Shop layout

7.3 Most UK fabrication shops have been built in a piecemeal fashion over many years, resulting in multiple small shops rather than the large shops favoured in completely new factories built since 1946, such as those in Italy (see Appendix F; Chapters 11, 12 and Annex H). Moreover, the general attitude towards pressure vessel fabrication in the UK, involving both a lack of specialisation and a lack of rationalisation as between different factories, does not favour the layout of shops for efficiency in production of particular types of vessel. Even so there is a general sequence of events common to all pressure vessel manufacture such that, even in a jobbing shop, good layout is beneficial. For example, the shops should be planned so as to minimise the frequency of occurrence of that slow operation—the transference of vessels from bay to bay—and such planning would favour the use of long shops. The Committee considers that poor shop layout is a major feature limiting the efficiency of many pressure vessel fabricators.

We therefore recommend that

> the pressure vessel fabricators take steps to provide new, large well-planned workshops (see also paragraphs 7.19 – 7.24).

Management and professional staff

7.4 The economic survey was very critical of the lack of initiative shown by the directors and senior management of many UK pressure vessel fabricators, in particular, that there were proportionately fewer young engineers with degrees or equivalent qualifications in managerial positions, compared with practice on the Continent. The Committee accepted these comments and further noted that even fewer were trained professionally as managers. There are of course exceptions, and it is notable that the exceptions are those companies showing the most vigorous development as well as appearing to have low levels of complaints from customers. If the industry is to attract into its mangement more active and highly qualified men, it must improve its image and its rewards. The career opportunities which a small fabricating company can offer are necessarily limited, and this is another aspect from which considerable gains could result through well-planned rationalisation of the industry (see paragraphs 7.19 – 7.24).

7.5 If the industry follows the Committee's suggestion that there should be more concentration on vessels involving innovation and high added value, it will need a strong professional staff. For example, the size and quality of the design team is very important. Comments from customers indicate that drafting and design facilities are, except in certain companies, insufficient to deal with more sophisticated enquiries. This is another important aspect to be considered when planning the rationalisation of the industry.

Labour and labour relations

7.6 Nearly 90% of 23 fabricators drawn from the questionnaire analysis reported in Appendix F (Annex B) considered that the availability of skilled labour was the limiting factor in their production capacity in 1966. There is little point in exhorting these companies to adopt shift working to use their equipment more efficiently if they cannot get the required personnel. There are regional differences, and the situation is worst where it is easy for personnel to find alternative employment. In such localities, the companies lose men unless they offer the traditional working week, consisting of day shift only with the desired numbers of overtime hours. This provides a severe operating limitation in a fluctuating market and it restricts the efficiency of the industry. This regional variation could be a feature of importance when considering rationalisation; it may prove easier to move the work than to move the skilled workers.

7.7 Heavy fabrication work is arduous and demanding, and often done in hot and cramped conditions, and men can often find easier jobs offering as much or more money. It appears commonplace that skilled men laid off by the industry during times of low demand (as in 1963) do not return to the industry and that some firms rely on an ageing work-force. These problems make it important that the industry should offer continuous employment prospects and should use its skilled labour to maximum advantage.

7.8 The full use of skilled labour implies flexibility between trades, the acceptance of labour-saving techniques and advanced machinery, and the acceptance of methods of production control and work study. Many companies have met with considerable resistance iu such matters, partly because of the fears of redundancy fortified by periodic experiences of low demand.

7.9 The biggest difference between labour relationships in the UK and in the major competing European countries is that only in the UK does a practise of demarcation exist restricting the flexible use of skilled labour (see Appendix F; Chapter 18). This applies to demarcation between unions and to demarcation between different skills in the same union. This has detrimental effects on the efficiency of working, since the variations in requirements between one pressure vessel and another, and at different times on any one vessel, lead to variations in the amount of work for any particular trade. This could be alleviated by the formation of a pool of skilled workers who individually could be transferred from plating operations to welding operations as production required; by allowing platers and welders to undertake the simpler parts of each other's tasks as the need arose; and by allowing any skilled man to carry out such unskilled work as may form part of his overall task.

7.10 It should be noted that the headquarters staff of the relevant uuions (in the main the Boilermakers Society and the Amalgamated Engineering Union) are receptive to such changes and are anxious to see the efficient use of labour. The difficulties arise at the local level, and there are often differences between one shop and another in the same region. Much appears to depend on individual management attitudes and on management/union relationships. It is perhaps relevant that countries with records of the most co-operative labour (e.g. Italy and Japan) also have good records in having responsible approaches to labour and in providing security of employment; similar relationships can exist at the company level. Much also depends on the vigour and patience of management in pursuing schemes for the more efficient use of labour. It appears that the more determined and progressive companies do finally get agreement to what they want, in contrast with other managements that passively accept the existing position. Nevertheless, the Committee accepts that the UK pressure vessel industry will not be able to compete effectively with those of the Continent unless demarcation and other restrictive practices are replaced by a positive approach to the efficient use of skilled labour. This includes introduction of work study, work measurement and related payment schemes.

We therefore recommend that

(i) the Minister of Employment and Productivity be informed of the concern of the Committee of Enquiry over the present situation with regard to demarcation within the pressure vessel industry;

(ii) TIPA be invited to make arrangements for management training courses for its members, covering the various aspects mentioned in this Chapter and stressing the responsibility of management for improving personnel relations and so increasing productivity;

(iii) the various unions be asked to consider what steps they can take to increase productivity in practice;

(iv) representatives of the Engineering Employers Federation and of the appropriate unions be invited to meet to establish the principles of agreements to obviate demarcation difficulties, and on other aspects related to the increase of productivity.

Commercial aspects

7.11 Shortcomings in some fabricators spring from the lack of use by their managements of modern costing techniques to enable the selection of items or tenders of highest potential profitability. They may not keep statistics of output by product category, nor allocate the overheads accurately, so concealing the various profitabilities of their different products. The economic survey indicates that the screening of requests for tender is generally low (see Appendix F; Chapter 4) so that, although considerable effort is spent on preparing estimates, the degree of detail covered in an individual estimate can be very much less than that covered by some foreign fabricators. Two aspects require emphasis—the lack of real production data and historical costs and the difficulties in attributing overheads (see Appendix F; Chapter 4). However, the more progressive of the UK pressure vessel fabricators have developed sophisticated schemes. TIPA can encourage exchange of information on these techniques, but real improvement would follow the rationalisation of the industry into larger units.

7.12 Comment has already been made on the general need to apply more modern methods of production control. These should also be associated with planning the use of the facilities, although admittedly this becomes difficult if the shop layout is intrinsically poor. The need for improvement is indicated by the low proportion of total working time for which no work is actually done on a particular vessel. In many companies in the UK for more than half of the *working* hours the vessel was *not* receiving any added value and was simply occupying expensive factory space. With good planning, including that of the supply of the bought-in components, it should be possible to improve the time during which a vessel is worked upon towards a practical, desirable figure of about 75% of the working hours.

7.13 One way of increasing efficiency and of decreasing unit overheads is to use shift work. Whilst 24 hour shift work is commonplace in Italy, three-quarters of the UK companies returning questionnaires only worked a day shift and tbe remainder generally worked two shifts. There is resistance to shift working throughout the industry but a significant further reason for absence of shift working was shortage of personnel and many companies could not find tbe labour for one full shift. In this respect it should be noted that several foreign countries have made use of immigrant or visiting labour recruited abroad. However, the necessary labour for shift working in the UK could be made available by extensive redeployment and re-training of personnel at present in the over-manned industries. The Committee considers that the provision of sufficient skilled labour to make shift-work possible would be a major step towards increasing the efficiency of the pressure vessel industry.

Training

7.14 The shortage of skilled labour emphasizes the importance of training arrangements. The traditional apprenticeship system, which is the major source of skilled labour in the UK, produces craftsmen of high quality. Moreover, training is currently being made more effective as a result of the Industrial Training Boards and the associated financial rebates. The only change to these schemes suggested by the Committee is that the more able apprentices should normally be expected to become multiple-trade craftsmen.

7.15 The need for skilled labour and for redeployment necessitates provision of opportunities for the re-training of mature men who, when they achieved the appropriate standard should be recognised by both unions and management.

We therefore recommend that

(i) the Government, in executing its redeployment and re-training policy, takes note of the difficulties in obtaining labour for the pressure vessel industry;

(ii) the Government provides increased facilities for retraining personnel in fabrication skills;

(iii) the Government discusses with representatives of the trade associations and of the unions the best way of applying such a policy;

(iv) if (i) to (iii) above were to be unsuccessful, then the Government should consider the advantages and disadvantages resulting from recruiting personnel from abroad, to work in the pressure vessel industry, and to take the appropriate action.

Technical aspects

7.16 Perhaps the most important technical point is that the desired trend of the pressure vessel industry, towards increased output of more sophisticated vessels, will necessitate the use of advanced fabrication techniques. The use of thicker sections, larger vessels and more difficult materials such as alloy and heat-treated steels all make higher technical demands on the fabricators. These demands are not fully appreciated by the smaller companies, especially those only used to simple mild steel fabrications.

7.17 More sophisticated vessels require more precise control to minimise defects, and so put an increased responsibility for quality on the managements and on their inspectors. Similarly the raising of design stresses may also increase the quality requirements. There is thus increasing need for the assessment of capabilities of individual fabricators to manufacture different types of pressure vessel. This need is implied in the current BS 1515 but no method of assessing competency of fabricators is stated in the standard.

We therefore recommend that

(i) fabricators be assessed for competance to manufacture different types of pressure vessel; such assessment should be accepted as a definition of competence where relevant to standards or to legal requirements;

(ii) the competency requirements and their methods of assessment for different types of vessel be agreed at a national level and reviewed regularly, and a statement of current requirements be made available to all interested parties;

(iii) a register of competent fabricators showing their relevant competency be published annually;

(iv) the actions recommended in (i) to (iii) above be arranged and supervised by the Pressure Vessel Authority proposed in Chapter 13.

7.18 This and other problems of fabrication development are referred to in the recommendations of the 'Working Group on Welding of Pressure Vessels of the Ministry of Technology' and are discussed further in Chapter 9 (Research and Development). The Committee of Enquiry notes with satisfaction that the Ministry has followed the recommendations of the Working Group by making arrangements to assist with the assessment and industrial application of new techniques and materials. The Committee considers it to be most desirable to make assessments of the relative applications of various techniques against real industrial backgrounds.

We therefore recommend that

(i) the Ministry of Technology initiates a comparative assessment of different techniques of welding, preparation and inspection of pressure vessels;

(ii) this activity be supervised by one of the Committees proposed in Chapter 13, making use as far as possible of the Ministry of Technology's Technical Group on Welding.

Rationalisation

7.19 The analysis of the structure of the UK pressure vessel industry (given in Chapter 3) showed the existence of a large number of small companies, and indicated that the average size of units was smaller than in competitive foreign countries.

7.20 The only information presented to the Committee specifically giving output per man values (see Appendix F, Table 3(2)) showed that the average output per man-year in UK heavy fabrication shops increased from £3800 for shops each averaging 63 workers, to £6900 for shops averaging 350 workers. This occurred in spite of smaller companies working a longer working week than larger companies. Whilst some of the increases in output per man arose from more sophisticated vessels being made in the larger shops, it indicated the advantages that would result if the industry were to be rationalised so as to reduce the number of smaller shops. The Committee notes that some rationalisation had already occurred by mid-1968, but believes it could with benefit be extended.

7.21 Other advantages that could result from merging and rationalising the industry are the sharing and improvement: of design and computer facilities (paragraph 6.5 and 10.46); of commercial and production planning services (paragraphs 5.14 and 6.4); of equipment especially that of a specialised nature (paragraph 7.2); and of R & D facilities (paragraph 9.14). The resulting larger companies should have improved management and be able to offer better career possibilities to managerial and professional staff (paragraph 7.4).

7.22 The biggest advantage to the industry in the long term would arise if rationalisation were to be accompanied by declared specialisation in particular types of vessels at particular shops. This would enable the centralisation of appropriate equipment and the planning of workshops and of material supplies in ways best suited to the specialised product. It would also encourage better contact between specialist sales and design staff with their corresponding customers.

7.23 Further information is needed on which to base detailed recommendations for specific reorganisation of the pressure vessel industry. One essential item is more information on the types of pressure vessel likely to be required over the next ten years, and the Committee has made a recommendation in paragraph 4.3 for such an assessment to be made. However, the need for change is immediate and discussions should not be delayed for completion of this assessment. In general terms the reorganisation should aim at the production of about four groups of companies, with individual specialisation within these groups. This will be sufficient to give contractors some freedom of choice, whilst reducing the amount of unnecessary duplication. Appropriate group-screening to identify tenders for quotation would immediately reduce the wasteful and costly preparation of unsuccessful tenders. It should allow fewer estimates to be prepared but in greater detail. It could also balance the need for a good 'mix' of different types of vessels within a group to permit a high level of technical innovation coupled with good overall profitability, whilst still permitting the increased efficiency from specialisation at a particular site.

7.24 Some of the many other factors to be taken into account are: the regional distribution of availability of skilled labour; the problem of transport for the desired higher level of exports; the positioning of new, well-planned workshops; and co-operation with other industries. Whilst the Committee attaches great importance to the need to reorganise the pressure vessel industry into fewer, larger groups, it considers it to be outside its competence to make specific and detailed recommendations. It is emphasised that the Committee considers an immediate reorganisation as being the most important change needed in the pressure vessel industry.

We therefore recommend that

(i) the Industrial Reorganisation Corporation be asked to discuss with the pressure vessel industry as a matter of urgency that reorganisation of the heavy fabrication industry deemed appropriate according to the aims of paragraphs 7.19 – 7.24, and to take the necessary steps to achieve this reorganisation;

(ii) the Government should consider means of providing financial assistance to rationalised undertakings for the provision of new fabrication shops (see paragraph 7.3).

CHAPTER 8

Materials—the supply of plate and consumables

Sources of information

8.1 There was considerable comment on materials aspects in the replies to the general enquiry letter (see Appendix E). These replies stressed the importance of materials supply with respect to cost and delivery of pressure vessels, and made a number of complaints. Further comments were made in various other submissions to the Committee. Since these various comments were mainly of a generalised nature, the Committee prepared a questionnaire aimed at providing detailed and specific information on the difficulties associated with the supply of steel plate and forgings. This questionnaire was sent to the members of the relevant Trade Associations covering fabricators and materials users. There was a good response to this questionnaire and the replies are summarised in Appendix L. From these replies the Committee ascertained the important criticisms and put these to the steel supply industry for comment. The replies from the steel industry are also summarised in Appendix L. Further information on steel supply, particularly that in other countries, was also obtained from the economic survey.

8.2 A similar procedure was adopted with criticisms on welding consumables. More detailed comments were obtained from the fabricators and from the manufacturers of consumables in response to a questionnaire; these are summarised in Appendix M.

8.3 No criticism or comment was received on the supply of non-ferrous metal for pressure vessels. The Committee therefore assumed that the position was satisfactory and took no further action.

British steel standards and specifications

8.4 In submissions to the Committee were criticisms of the multiplicity of overlapping steel standards and specifications. However, the pressure vessel manufacturers accepted in late 1967 that the revised versions of BS1501, 1502, 1503, 3059, 3602, 3604 and 3605 would provide a satisfactory and rational series of steel standards. The early replies suggested that smaller fabricators were not fully aware of recent developments, a situation that could be avoided in future through appropriate action by the pressure vessel division of TIPA proposed in paragraph 3.13.

8.5 There was considerable criticism of the delay in completing these revisions, and emphasis was laid on the need for similar standards in the BS 1501 series providing specifications for proprietary steels, stainless steels and 9% nickel steel. The steel makers were also concerned about these delays, which they considered to be due: to insufficient staff at BSI; to unnecessarily long intervals between BSI standards committee meetings; to the cumbersome procedure of large unwieldy committees; and to the fact that the procedure of immediate circulation of draft standards proposed in the Bowlby Report had not been implemented. These comments parallel similar comments relating to pressure vessel design standards and are discussed further in Chapter 12, which emphasises the responsibilities of industry in respect of the operation of BSI.

Available range of steels

8.6 Many of the original submissions considered that the range of steels available in the UK was less than in other countries, particularly of high strength structural steels. However, the Committee considers, on the basis of more detailed questioning of the fabricators and of the replies from the steelmakers, that provided proprietary steels were taken into account the range of steels in the UK is adequate and quite comparable with that available abroad. This conclusion is illustrated graphically in Figs. 1A, 1B, 2A, 2B given in Appendix L which compare, at different service temperatures, the strength ranges of steels available in the UK and in the Federal Republic of Germany. The above conclusion assumes of course that steels over the whole range offered can in fact be obtained at a reasonable price and delivery; many users stated that some of the proprietary steels were not commercially competitive with foreign steels.

8.7 Even so it may be necessary, for example with orders for foreign customers, to use steel made to foreign standards or specifications. In reply to questions on the availability of such steels, the steel industry stated that orders to foreign standards or specifications will be accepted on the same basis as those to British standards or specifications, without any extra premium or longer delivery period *per se*. Users may still prefer to obtain such steels from abroad because of lower prices. A particular point on the use of foreign standards or specifications is that US standard code numbers for stainless steel appear to be in wider use in the UK than the corresponding BS numbers. Certainly the use of such numbers should not cause delay, and indeed the numbers should be recognised officially by BSI.

We therefore recommend that

> the American Iron and Steel Institute (AISI) reference numbers for stainless steels be accepted officially as appropriate reference numbers for such steels, and that the BS be modified accordingly.

Demand and supply aspects

8.8 It is important to realise that in terms of tonnage of steel consumed, the pressure vessel industry uses only a relatively small fraction of the total output of steel plate. Data provided by steel-makers shows that they supplied approximately 200 000 tons of plate to the pressure vessel industry out of a total plate production of approximately 3 million tons. The majority of the 200 000 tons production was relatively simple carbon-manganese steel; alloy and special steel plate totalled less than 20 000 tons. Special orders included not only special steel compositions but also special requirements for wide and thick plate.

8.9 As indicated in the demand survey, it is unlikely that future annual demand for vessels over the next ten years will be any greater than in 1966, although it may be expected that a decreased proportion of this demand will be for carbon and carbon-manganese steels, together with increased requirements for the more sophisticated steels. The 1966 total for low-alloy steels of 15 000 tons divided between four producers (see Table 4) is not large, particularly when it is remembered that high quality is required as well as the involvement of a large amount of technical work and data collection. There is one steel plant in the industry which appears to be in a dominant position in the supply of wide, thick plate in alloy and special steels. This steel plant is also able to supply electric furnace and vacuum degassed steel.

8.10 The fabricators complained about the supply of special steels such as 9 % nickel, stainless-clad plate and quenched and tempered plate. The steelmakers provided fairly detailed answers to these complaints. In 1966 the total demand for 3½ % and 9 % nickel steels was only 445 tons. With low and infrequent demand for materials high in alloying elements (which may be in short supply) the steel industry would welcome greater notice of requirements. No overall figures are available for stainless steel, but one supplier made 2500 tons of plate for presure vessels. Regarding stainless clad-plate, there appears to be a manufacturing capacity of 5000 tons as at 1967, against a demand of 2000 tons. Similarly the steelmakers stated there was good capacity for quenched and tempered steels with yield strengths from 23 to 45 tons/in^2, and these are being manufactured in large tonnages. There has been little demand or interest in these steels from the pressure vessel industry because, until recently, the industry believed the output of these steels was fully used for other products.

8.11 Turning to the manufacturing process, whilst in the past supplies of electric furnace and of vacuum degassed plate have been limited, the position had improved markedly in the last few years. It appeared that the requirements of the pressure vessel industry for vacuum degassed steel could now be met with plates up to 20 tons weight. The standard charge for vacuum degassing is £2 per ton.

8.12 There were also complaints of the weights and sizes of plates available from UK manufacturers, since smaller plates involved both more welding and higher costs. The biggest plates of constructional steel available in the UK in 1967 were up to 20 tons in weight (to be increased to 25 tons in 1968) and 156 in. wide from a single manufacturer, the actual maximum size depending on thickness. These sizes are comparable with those from other steelmills throughout the world except for a few steelworks (2 in the USA, 1 in the Federal Republic of Germany, 1 in Japan) where very large plates (over 180 in. finished width) can be handled. It was reported that the very wide mills are not ideal for making narrower plate, and an installation in the USA had a moveable housing which could be adjusted from 160 to 210 in. rolling width. The availability of heavy, wide, thick plates in the USA is closely associated with the construction of steel reactor pressure vessels in their nuclear programme, and it must be noted that in the UK there was only a small and infrequent demand for such heavy plate. The UK fabricators also complained of the limitations in size of stainless-steel plates, the maximum available size of which varied with thickness and composition but corresponded to plates of a maximum weight of about 3½ tons and up to 8 ft. in width. Stainless steel plates of about twice the maximum UK plate weight can be obtained from Sweden.

TABLE 4. Tonnage of pressure vessel steels supplied by major UK manufacturers in 1966

Maker	Tons			
	C and C-Mn steels	3½ and 9% Ni Steels	Proprietary Steels	Low Alloy Steels (e.g. ½%Mo; 1% Cr ½%Mo; 2¼% Cr 1% Mo etc.)
1	52 159	Nil	1682	574
2	70 000	35	3950	5400
3	25 000	410	2650	50
4	35 462	Nil	Nil	702
TOTAL	182 621	445	8281	6726

8.13 The Committee considers that the position on the UK steel supply is not now as bad as had been indicated by the number of complaints. In some respects this was because of improvements in facilities over the period 1966–8, particularly that of vacuum degassing. In other respects the difference may have arisen because the steel industry was not working at full activity in 1968 and was more willing to consider special steels. Some of the difference arises from poor communications and lack of strong representation by pressure vessel fabricators to the steel industry of their special requirements. These problems could be reduced by suitable rationalisation of both the pressure vessel and the steel industries, and with appropriate action from the pressure vessel division of TIPA as proposed in paragraph 3.13.

We therefore recommend that

> the pressure vessel division of TIPA nominates representatives to keep the British Steel Corporation, and any other relevant suppliers, informed of the technical requirements of the pressure vessel industry, including demand predictions particularly for larger sizes of plate and for special qualities of steel.

Steel delivery

8.14 The replies to the general enquiry letter of February, 1967 frequently complained of long delivery periods for steel plate, particularly on special qualities. It was apparent from the replies of fabricators to the detailed materials questionnaire of June, 1967 that there had been improvements. Delivery periods quoted were 8–16 weeks for special grades, as against 2–6 weeks for standard steels. The steelmakers, whose main reply to the steel supply questionnaire was not received until January, 1968, also quoted 2–6 weeks for standard steels with simple C and C-Mn steels at the short end of this delivery range and impact-tested or high-temperature-tested steels at the longer end. Delivery periods were quoted of 6–12 weeks for low alloy plate, 3½% and 9% Ni and stainless clad plate, and of 6–10 weeks for stainless steel. These figures contrasted with the reports of fabricators' experiences during 1966–7, which often indicated delivery periods of more than 3 months for normal qualities and up to 6 months for stainless steel plates.

8.15 A major complaint from pressure vessel fabricators was that replacements for defective steel plates increased the quoted delivery times by up to 4 months. The steelmakers admitted this could add to the delivery period and suggested, against the background existing at the time of their reply in January, 1968, that the increase in delivery time would be up to 4 weeks. This problem would become less important if the number of defective plates supplied to fabricators were reduced by detection of defects at the steelworks.

8.16 The above differences probably represent the real change in delivery position resulting from the reduction in loading of the steel industry from 1966 to 1967. Whilst the Committee regards the present position (mid-1968) as satisfactory, it is concerned lest the pressure vessel industry should again suffer long deliveries when activity in the steel industry again increased. The importance of the difference between 6 and 16 weeks in steel delivery is emphasised by the fact that delivery periods for the various pressure vessels quoted in Appendix F (Annex F) ranged from 4 to 40 weeks. Also the examples quoted in paragraph 6.3 showed that about a third of the late deliveries of pressure vessels arose from materials supply delays. Increased stock-holding, at least of special steels, would be beneficial in this respect. However, the range of sizes demanded by the pressure vessel industry is very large. The Committee considered the possibility of standardising on a reduced number of sizes and thicknesses, but this did not appear to be economically practicable. The total quantities involved did not justify significant stocks in numerous places.

We therefore recommend that

(i) the British Steel Corporation, together with the pressure vessel division of TIPA, should look into the feasibility of the holding of stocks of slabs, suitable for the manufacture of special plate for pressure vessel use, by selected steelmaking plants;

(ii) the BSC be invited to note the problems created by delays in replacing defective plate, to discuss this problem with TIPA representatives, and to take appropriate steps.

Documentation and identification

8.17 There were various complaints that steelmakers were reluctant to accept special requirements or to provide special documentation without delay. The steelmakers replied that all plate-makers were prepared to undertake such special testing requirements or documentation provided that such requirements were declared at the time of enquiry. However, this reply could again have been affected by the state of loading of the industry, in 1967, and the detailed replies were somewhat qualified. The steelmakers should appreciate that fabricators did not request such documentation irresponsibly; the documents were usually a condition in the supply of vessels to foreign buyers and as such must be provided. This was an aspect that must be given attention with the increasing importance of exports.

8.18 It is also important that such documents, whether normal or special, should arrive with the plate instead of several weeks in arrears as sometimes happened. The information in the documents could affect the use of the plates, since details of the fabrication process might have to be altered to avoid failure in fabrication.

8.19 It was also claimed to be difficult or impossible to identify the plate number on at least 5% of the plates delivered for pressure vessel fabrication. In this respect, it is noted that identification numbers should not be applied so close to the edge of plates that they are removed during edge preparation.

We therefore recommend that

(i) BSC be invited to improve their method of plate identification and to review their documentation procedures so as to provide prompt and full documentation even when special requirements are called for;

(ii) TIPA advises its members to insist on the provision of adequate documentation with the supply of steel plates, and on the adequate identification of these plates.

Defective plate

8.20 Some of the most forthright comments related to the supply of defective plate. Numerous specific examples were quoted in submissions to the Committee of Enquiry, one of which stated that the quality provided by Swedish, German, American and Japanese steelmills was generally superior to that of their British counterparts, and referred to the very poor service and quality provided on many occasions by the British steel industry. A quantitative statement provided by one fabricator indicated that of 260 000 tons of plate received between January, 1960 and April, 1967, about 3600 tons were rejected (at the fabricator's works) as defective. It must be emphasised that this quantity, representing an average of 1·4% of the whole, was not the overall reject rate of the product, but the quantity supplied by the steelmakers as satisfactory which later had to be replaced. The detailed submissions continued to make these complaints, indicating no real trend of improvement with time, and indeed for some of the most important companies in the pressure vessel industry, this was the major complaint made.

8.21 The main defect referred to above was, in general terms, poor steel cleanliness. The steelmakers did not give any detailed answers to these criticisms. They claimed equal cleanliness with foreign steelmakers when comparing similar processes or 'like-for-like'. On the other hand the fabricator was essentially interested in the product, not the process. Satisfactory clean pressure vessel plate had been available from Japan for several years, produced by electric arc steelmaking and then by cheaper processes followed by vacuum degassing. Similar developments had taken place in Germany and Italy shortly thereafterwards, whereas vacuum degassed steel plate had only recently become available in the UK. The Committee hopes that the availability of UK vacuum-degassed plate improves a situation which it regards as very unsatisfactory for fabricators.

8.22 An associated question is that of the 20% premium charged for full ultrasonic testing. The steelmakers justify this extra charge in terms of extra cost of testing and of greater rejection risk. The former aspect is known to be small, and it is understood that the risk of rejection can become very low with the use of vacuum degassing which itself only costs an extra £2 per ton. Protected by the 20% premium however, the steel companies have not been encouraged to make the improvement in production process (which they could have adopted at any time in the last five years) to provide a major improvement in quality at little extra cost.

8.23 In the interests of national productivity it is clearly desirable that defects be reduced to a minimum and those that remain be detected at the earliest possible stage, to avoid expensive work and transport of defective material. It would also avoid delays to fabrication schedules arising when plate is found to be defective at the fabricators' works. The most important aspect, however, is that inspection at the steelworks encourages the direct feedback of information to steelwork's management whenever improvements are necessary. It is also important to note that in other countries, in general, no specific charge is made for ultrasonic inspection at steelworks. The Committee is strongly of the opinion that the 20% charge is undesirable and acts against the best interests of both the heavy fabrication industry and the steel industry.

We therefore recommend that

(i) the BSC notes the importance attached by the pressure vessel industry to cleanliness in steel plate; in this respect the attention of fabricators should be drawn to the availability and advantages of vacuum-degassed plate;

(ii) the Government applies the strongest possible pressure on the British Steel Industry: (a) to reduce substantially their premium for ultrasonic testing, and (b) to provide satisfactory facilities for ultrasonic inspection at the steelworks, to standards to be agreed, of all pressure vessel plate supplied to certain standards or specifications (see paragraph 8.21);

(iii) the need for further work on cleanliness and inspection of steel plate be emphasised to those organisations planning future R & D work for the pressure vessel and steel industries.

8.24 Some fabricators would also like to know the position in a plate of defects smaller than the size leading to rejection of the plate. If this information is not provided the fabricator may consider it necessary to repeat the ultrasonic inspection. The Committee recognises these are practical difficulties in deciding on the limiting sizes for reporting or rejection.

We therefore recommend that

(i) representatives of the BSC and of the pressure vessel industry meet to agree acceptable levels of cleanliness as well as suitable methods for reporting the results of ultrasonic tests on individual plates;

(ii) such standards of acceptance be authorised and reviewed regularly by the Pressure Vessel Authority proposed in Chapter 13.

Chemical composition

8.25 The only aspects of chemical composition on which comments were received related to carbon and carbon equivalent, and to sulphur and phosphorus levels. The references to carbon and carbon equivalent are associated with variations in weldability. The Committee notes with satisfaction the increased attention given to the question of weldability through the activities of both the Heavy Steel Association and the steelmakers' Weldability Group working in collaboration with the Welding Institute. However, there appeared to be little guidance from the pressure vessel industry about welding requirements and this situation could be improved by the proposed pressure vessel division of TIPA.

We therefore recommend that

the pressure vessel division of TIPA collects information and provides appropriate guidance to the steel suppliers about weldability requirements of the pressure vessel industry.

8.26 Weldability is of increasing importance with increasing strength, thickness and alloy content of pressure vessel steels. If the most economic processes are to be used, the fabricator must know the weldability of the particular piece of steel being used. A difficulty is that in the UK the analyses provided are ladle analyses, and considerable differences can arise between ladle analyses and analyses made in particular areas of the actual plate. At the very least there is a need for precise statistical information on the range of composition to be expected with each steel specification and product form, particularly for plates thicker than 2 in. This is a problem that will increase with increasing interest in more sophisticated vessels.

We therefore recommend that

the steelmakers be asked to provide statistical information on the actual local composition limits to be expected for each steel specification and product form.

Steel property data

8.27 It appears that availability of data on steel properties at elevated temperatures is satisfactory. The question of minimum property levels is discussed under design stresses in Chapter 10. The Committee notes with satisfaction the efforts of the British Steelmakers Creep Committee and the results published at their Eastbourne Conference in 1966. One remaining topic requiring more information is that of rupture ductility of weldments, and especially its variation with plate composition.

8.28 In spite of the initiative of the Heavy Steel Association there still appears to be a real need for additional information on the notch ductility or fracture toughness properties of the newer steels, and even for the well-established steels in thick sections. Knowledge of the effects of welding on local fracture toughness and of thermal stress relief on as-welded properties is also limited. Detailed planning of how best to obtain such information may be left to the technical discussions between TIPA and BSC proposed in paragraph 8.13.

Commercial aspects

8.29 Some replies to the questionnaire criticised the complexity of the pricing system for British steel with its many extras. It is claimed that British price schedules produce bigger differences in price between alloy (particularly low alloy) and carbon steels than exist on the Continent, which means that British fabricators are placed at a disadvantage in using low alloy steels. It is also claimed that the extra price imposed for UK killed steel makes such steel uncompetitive with Continental killed steel, this comment being particularly directed at BS 1501: 161 and 221. It was difficult for the Committee to obtain precise information on these criticisms because of the varying prices and specified properties of the Continental steels. Nevertheless, it is clearly desirable that the methods used for pricing steels should result in a logical pattern from the point of view of 'design strength/cost' and that such UK steels should be competitive with Continental steels.

We therefore recommend that

> the BSC be asked to review their methods of pricing in order to remove anomalies between carbon and alloy steels and between balanced and killed steels; the objectives are to produce a logical range of steels on the basis of 'design strength/cost' and to ensure that such UK steels are competitive with Continental steels.

8.30 A source of resentment and irritation to UK fabricators is the fact that UK steelmakers allow an export reduction in price to foreign buyers of pressure vessel steel, possibly in cases where the buyers are in direct competition with UK fabricators. UK fabricators cannot obtain UK steel at the lower export prices even on vessels being built for export. This is particularly important in view of the large fraction that material cost constitutes of total vessel cost (see paragraph 2.2). The fabricators argue it is in the national interest to export steel in the higher-value fabricated state, and that they should buy steel at least for such jobs at export prices, which in some cases have been 20% lower than the corresponding internal UK steel prices. In exchanges with the Committee, the BSC notes there are many difficulties in devising and operating an equitable scheme but, nevertheless, the BSC has agreed to discuss the position with representatives of the pressure vessel industry. The Committee considers this could best be done by members of a pressure vessel division of TIPA.

General comment on plate supply

8.31 Many of the difficulties referred to in the preceding paragraphs arise from the special requirements of the pressure vessel industry and in the difficulties of communicating with such a diverse industry. The proposed rationalisation of the industry (paragraph 7.23) and the proposal for organised representation through a division of TIPA (paragraph 3.13) should help considerably. Study of the supply of pressure vessel plate in other countries has shown their tendency to concentrate this type of production in special works, many of which are organisationally linked to fabricators and even located adjacent to fabrication shops. It is perhaps these factors which have led elsewhere to the more speedy adoption of processes producing clean steel. The position in the UK is almost the opposite, with problems arising from the manufacture of special steel plate in steel works planned essentially for bulk production, together with a lack of any organisational links. Indeed, the position in the UK could become worse as rationalisation within the steel industry concentrates on still larger production units. The total tonnage of special plate steels required by the pressure vessel industry is small and there might be advantages if production were to be concentrated in one specially equipped steel works. Whether this were feasible or not, the Committee considers it important to ensure that, during the re-planning of production facilities in the steel industry, by the BSC, the special steel requirements of the pressure vessel industry should be kept in mind.

We therefore recommend that

> the Government brings to the notice of the BSC the special steel requirements of the pressure vessel industry and emphasises these be taken into account in the re-planning of steel production facilities.

8.32 The Committee notes the difficulties associated with the introduction of new materials into practical use, and discusses this aspect in Chapter 9.

Welding consumables (electrodes)

8.33 Information on welding consumables was obtained through questionnaires sent to electrode manufacturers and to fabricators (see Appendix M), from whom replies were received during February–March 1968.

8.34 It is considered that a satisfactory range of manual electrodes for general purposes can be obtained in the UK, providing one included not only wholly British manufacturers but also companies that manufacture in the UK with technical support from overseas, and also companies that sell electrodes in the UK that are made abroad. There are still difficulties in obtaining suitable electrodes for special purposes, such as a matching electrode for 9% Ni steel, and electrodes giving high notch toughness and good welding properties in site conditions for medium and higher strength steels and low alloy steels in thicknesses between 2 to 10 in. It appears that electrode manufacturers have rarely been involved with the development of such steels, so that electrodes for the newer steels have not become available at the same time as the steels. Advantage could be taken of the interests of the British Steelmakers Weldability Group, and of the growing interests of the British Iron and Steel Research Association, in welding problems arising during new steel development by the involvement of at least one electrode manufacturer in such work.

We therefore recommend that

> the BSC be invited to take steps to encourage the development of welding consumables concurrently with the development of new steels.

8.35 The position with regard to wires and fluxes for machine-welding processes is similar to that for manual electrodes. The range available in the UK for general purposes is satisfactory, even to the extent of a confusing multiplicity. There are however difficulties in obtaining materials to match new developments such as the high-proof stainless steels. The electrode manufacturers complain that they have difficulties in obtaining from the steelmakers any wires of special alloy compositions, with respect both to delays and to the minimum quantities that can be ordered. The electrode industry sometimes only requires a few pounds whereas the steelmakers regard even a few tons as embarrassingly small. This is part of a more general problem on how the steel industry might meet the very real demand for small quantities of essential special materials. With regard to welding wires, the position is somewhat easier with the growing use of cored wires in which alloy constitutents can be added to make up deficiencies in wire composition, although there are technical limitations to this technique.

8.36 The delivery situation for welding consumables was reported to be generally satisfactory, normal requirements being met ex-stock or within 2–3 weeks, and only a few special steels taking up to 3 months.

8.37 The position regarding data on elevated temperature properties of weld metal, especially in creep or creep-rupture tests, is very poor and compares most unfavourably with the information available on steel plate. The position is little better with respect to low temperature properties, certainly considering tests other than the V-notch impact test. The electrode manufacturers point out the high cost of such work when related to the small quantities of material involved. Nevertheless individually they resist collaboration with other electrode manufacturers to share the costs of such work. Indeed the degree of technical exchange between electrode manufacturers appears significantly less than within other sectors of industry, although there appears to be a willingness to collaborate technically with these other sectors. The general impression is that electrode manufacturers are unwilling to collaborate with each other in providing the extensive information required on their products, and furthermore they find it difficult to justify such work on an individual basis. As a result fabricators are forced to do the work with inevitable duplication. The Committee considers there is room for considerable improvement in the attitude of the electrode manufacturers. The Committee notes with satisfaction that the Ministry of Technology has initiated some action in this area.

We therefore recommend that

> the Ministry of Technology initiates and progresses action: (a) to increase the information available on high and low temperature properties of weldments, and (b) to increase technical collaboration between electrode manufacturers, and between such manufacturers and other relevant parties.

8.38 The specifications for and certification of electrodes and welding consumables appear to suffer from the same general problems as those relating to other materials as discussed in other paragraphs. Information available is often only for the 'downhand' welding position, whereas that for the vertical position is also required. There also appears to be a need for the independent assessment of performance claims made for new welding processes and materials. The Committee notes with satisfaction that means of providing such a service is the subject of discussion between the Ministry of Technology and the Welding Institute.

Miscellaneous

8.39 With regard to materials for non-ferrous pressure vessels, the attention of the Committee has been drawn (Appendix M) to the absence of welding wire of matching strength to NP8 (Al-Mg) plate. There has been little comment on ferrous materials (other than on plate and welding consumables) although the Committee understands that difficulties exist in obtaining ancillary fittings in some alloy steels, for example 9% nickel steel.

8.40 The present and future supply of dished and flanged ends in all materials of interest has been examined and it appears there is now an adequate UK manufacturing capacity. Whilst many comments were received to the effect that the supply of pressure vessel ends has caused delay, such delays were caused by the peak in demand during 1965–6. The TIPA has now published a restricted range of standard shapes for which the dished end suppliers are now making or modifying tools. If the use of standard ends is exploited it will mean that a larger fraction of ends for the simpler pressure vessels could be made economically on die presses, thus releasing capacity on spinning equipment which has been overloaded at times in the past.

8.41 The dished end supplier normally has to obtain materials involving long delivery. Quite often the supplier has to weld together two or more plates in order to provide a blank of sufficient size. Pressure vessel fabricators can help themselves by providing the dished end suppliers with circled blanks ready for spinning or pressing.

8.42 Dished ends are particularly important items in the production of pressure vessels since they are usually the first of the items required, and for this reason have been particularly susceptible to criticism. During 1968 some pressure vessel ends were still being purchased from overseas, partly on account of delivery but also partly because pressure vessels are increasing in size and some were above the common UK limit on size for pressing or spinning (see Annex B of Appendix F). The position regarding delivery of other than the simpler dished ends will only be improved when the plate from which they are formed is made more readily available. This can only be achieved by quicker delivery service from the steel mills, until such time as substantial standardisation of ends permits the dished end supplier to carry significant stocks of steel.

8.43 Some of the comments made on plate materials are also relevant to the forging industry. In particular the delay in producing standards for forgings has been rather greater than for plates. Furthermore the shortage of property data, particularly relating to such aspects as fracture, is more pronounced in the case of forgings. Certain other aspects should, on the other hand, give rise to less complaint. For instance, forgings are manufactured in works where alloy steel practice is used and these works are well equipped to supply electrically melted steel (which is cleaner) and to apply other processes such as vacuum degassing. With regard to delivery, the forge-masters stress that forgings are mainly made against specific orders, which latter vary considerably in quantity and type from year to year. The only difficulty likely to arise concerns the supply of small quantities when a particular analysis is not in regular production. In this respect standardisation would help, and TIPA undertook the preparation of some proposals for this in 1968.

8.44 The above remarks are based on comments received at the end of 1967, when forgemasters were very short of orders. The Committee understands that during periods of high demand the delivery period for forgings increases until forgings become the controlling item in pressure vessel delivery.

CHAPTER 9

Research and development

Sources of information

9.1 Following comments made in early submissions to the Committee of Enquiry, and in the report of the Ministry of Technology Working Group on Welding of Pressure Vessels, the Committee commissioned a survey by the UKAEA Reactor Materials Laboratory which involved the issue of two special questionnaires. The replies to these questionnaires are given in Appendix N. The Committee also made use of information on future research needs given in a paper entitled 'Current Pressure Vessel Problems' prepared by Drs. Fessler and Stanley of Nottingham University, and the discussion of that paper at the Institution of Mechanical Engineers in January 1968.

Amount of research and development

9.2 One difficulty in determining the amount of R & D on pressure vessel problems in progress in the UK is that of defining what actually constitutes R & D. In this Report a wide-ranging definition has been used, which includes almost all of the work done in relevant laboratories and R & D departments. It must be emphasised that the definition covers a whole spectrum of work ranging from basic research to fabrication process assessment following on the day-to-day change in jobs in the shops. Whilst it is difficult to provide quantitative support for such a view, the Committee believes that a considerable fraction of the work referred to in the present chapter as R & D is of the type more associated with day-to-day process assessment. This point must be remembered throughout the discussion of R & D.

9.3 Some difficulty arose in assessing the total quantity of pressure vessel R & D from replies to the two questionnaires. Indeed, many of the replies gave the impression that the organisations did not make any real attempt to cost their R & D activities accurately. An estimate of total R & D effort was prepared by using the stated manpower effort values together with the assumption that one qualified man (with direct charges the cost of supporting staff and overheads), costs about £8000. This figure, based on 1967 costs provided by the Ministry of Technology, is of the right order for most of the industry but somewhat high for university expenditure. However, the resulting overestimate is probably balanced by omissions from the manpower effort estimates caused by non-respondents.

9.4 The estimated annual expenditure on R & D by companies whose predominant activity is the manufacture of pressure vessels and similar plant is £1M. Other organisations, including pressure vessel users, material suppliers, public sector organisations and universities, undertake R & D to an estimated annual expenditure of £2·5M, although much of this research is not aimed specifically and solely at the pressure vessel market. This total of £3·5M per annum appears, from other Ministry of Technology statistics, to be a reasonable estimate and corresponds to the use of about 425 qualified men. The R & D expenditure by pressure vessel fabricators expressed as a proportion of their annual turnover of about £70M is about 1·5%, compared with a national average R & D expenditure of 2·7% of the gross national product. Allowance must be made for the additional contributions from other organisations, and the Committee concludes that the sum spent on R & D relevant to pressure vessels is satisfactory. This should not be taken to imply approval of the way in which this money is used.

9.5 Some of the £3·5M expenditure arises in direct grants from the Science Research Council to the Universities. A list of such grants for 1967 showed an annual expenditure of about £10 000 on aspects of pressure vessel design and behaviour and just less than £100 000 on material properties of interest to, but not restricted to, the field of pressure vessels (see Appendix N). This somewhat small sum specifically for pressure vessels does not represent the whole Government contribution. In addition to work for various departments, related to their specific needs, the Ministry of Technology provides general assistance to organisations such as the Welding Institute and the Non-Destructive Testing Centre, both of which work in this field. The Committee notes with satisfaction the announcement in 1968 by the Ministry of Technology of direct financial support to encourage industrial R & D aimed at proving the applications of new materials and new welding processes for the fabriaction of pressure vessels.

Distribution

9.6 The first R & D questionnaire was sent to 349 organisations, and a total of 268 were returned. Of these only 129 were active over the period 1962–6 on relevant R & D work. This total included 26 fabricators, 26 materials manufacturers, 41 university departments and 29 laboratories of users, public corporations, government departments and research associations.

9.7 The efforts deployed in the various laboratories varied greatly: 76 organisations used less than 10 qualified man-years effort spread over a period of 5 years; 36 organisations used between 10 and 50 man-years effort over a similar period; and 17 organisations used over 50 man-years effort also over a similar period. The latter 17 organisations accounted for about 40% of the total R & D effort, and of these only 8 organisations accounted for about 20% of the total effort. This corresponds to the pattern of output of shop-built pressure vessels, in which 6 fabricators accounted for 28% of the total output in the UK in 1966.

9.8 The following table indicates the percentage distribution of the R & D effort between different types of organisation (after weighting to allow for the different effort levels):

	Percentage Effort
Fabricators	29
Materials manufacturers	22
Universities etc.	16
Public corporations	12
Industrial users	6
Government departments	5
Research associations	4
Inspection organisations	4
Others	2

It should be noted that pressure vessel fabricators account for nearly a third of the effort, although much of their work is probably very closely associated with their immediate contracts.

9.9 Estimates comparing the five years (1967–71) with the five years (1962–6) show a small increase in total future effort by about 10%. This increase arises almost entirely from predictions of increased effort in the universities and is probably optimistic.

Subjects covered

9.10 The division of R & D activity between the main problem areas is shown in Fig. 2. This figure is illustrated in terms of numbers of organisations but 'weighting by effort' leads to a very similar pattern. The main conclusion is that the pattern does not change much with time, the only significant relative decrease being for R & D into techniques for manufacturing components. The two areas of greatest interest are those of determination of data, and of design aspects, each of these representing about a fifth of the total activity. The development of quality control techniques, of welding procedures, of materials and of component manufacture each accounts for about one eighth of the R & D effort.

9.11 The distribution of R & D work into various sub-sections of these main areas is discussed in more detail in Appendix N. In relation to determination of data, yield and tensile tests at various temperatures are the most common activities, with work on creep, fracture toughness and the properties of weldments almost as important, the last two subjects being studied particularly by pressure vessel fabricators. Work on fatigue and on corrosion problems is less than on the other subjects, and in all subjects there is more interest in determining data than in establishing the relevant failure criteria for each property.

9.12 Of the work related to design, elastic stress analysis is the most common activity, followed by rather less plastic analysis and very much less creep analysis. Future predictions indicate some growth in the last two subjects. Most of the studies of failure conditions relate to yield and bursting, with relatively little work on the effects of defect size on failure conditions. The work appears to be equally divided between the theoretical, the testing of small specimens and the testing of models. About three-quarters of the organisations interested in design

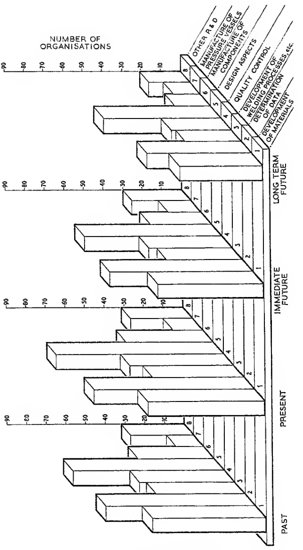

FIG. 2. Number of organisations working in each area of R & D

problems use computer techniques, and CEGB state they now have elastic/plastic solutions for the majority of shapes encountered in the pressure vessel industry, although the total expenditure in this area is less than £50 000 per annum. It is noticeable that the Universities devote more of their effort to design problems than to other subjects.

9.13 The subjects of interest to materials manufacturers are principally the development of steels, improvements in the quality of steel, and determination of data. The results often appear in trade publications and sales literature and a significant proportion are communicated to the British Standards Institution to help in the formulation of standards. There is also considerable publication in the technical literature. Work on the development of weld metals is done predominantly by the fabricators; moreover the electrode manufacturers do not publish much of their work. The need for improved collaboration between electrode manufacturers was emphasised earlier (paragraph 8.37).

9.14 The pressure vessel fabricators predominate with respect to work on welding processes, but much of this relates to learning how to use previously developed processes for their particular products. Even though such work is done in the fabricator's R & D department, it frequently has more application and training content than work usually regarded as R & D. There is considerable duplication of such work between the fabricators, and indeed each fabricator appears to be doing essentially similar work. Specific examples are: 7 organisations are working on electroslag welding; 5 on non-destructive testing and ultrasonics; and 4 on tube-to-plate joints and vessel cladding techniques. It is likely that duplication is more general than these few examples indicate. This duplication is associated with the development of technical 'know-how' and expertise at the shop floor level, including detailed appraisals to reduce difficulties in the shop. Another major reason for such work is the attempt to gain commercial advantage. The results of such work are in general only disseminated within the company, and are not issued in any form to an outside body. The Committee considers that, whilst this is understandable, it is doubtful whether the commercial gain is sufficiently long-term to compensate for the serious and unnecessary duplication of effort. Reduction of this duplication should be one of the objectives of the rationalisation of the industry referred to in Chapter 7. This will not be sufficient of itself to provide adequate communication between the various sections of the industry. A system is needed: to allow planning of R & D work to reduce the number of organisations undertaking work of given types; to identify (where desirable) a single organisation to assume responsibility for most of the work in a given subject; and to pool the R & D know-how obtained within reasonable limits. Proposals for a collaborative research organisation to provide such a system are made later in this Chapter.

9.15 Most of the large scale experimental testing is done by public corporations or organisations that are financed, at least in part, in various ways by the Government. This probably reflects the cost and long-term nature of such work. These organisations are also predominant in research related to failure mechanisms, to design concepts and to operational aspects. About 70% of the published literature references supplied to the research survey relate to work done by these organisations.

9.16 There is a high degree of fragmentation in pressure vessel research at Universities and other learned institutions, where the considerable total activity is divided among many small groups. This arises from well-known historical circumstances, in which each Department of each University has been free to carry out research on any topic in which it was interested, provided it could find sufficient resources to do so. This restriction of resources causes concentration on topics which can be investigated at small expense, accompanied by the neglect of other topics of equal or greater importance. In recent years the funds made available through the Science Research Council have markedly altered the possibilities of this situation, but much more could be done to change the immediate realities. The Committee recognises that it would be unwise and quite unnecessary to restrict the autonomy of Universities in such matters, but it is also of the opinion that many University Departments welcome opportunities to direct some of their activities towards particularly useful objectives. The Committee considers that the SRC should be informed of the present situation and asked not only to restrict support for projects which involve excessive duplication of effort but also to give positive guidance towards and financial encouragement of work in general areas identified as of value to the pressure vessel industry. In this task the proposed collaborative Research Organisation (paragraph 9.41) would of course be the appropriate body from which SRC Committees might themselves expect to receive guidance. The Committee of Enquiry appreciates that the SRC is anxious to adopt such positive policies and might be expected to welcome such guidance.

We therefore recommend that

(i) information be sought on what basic research would be most appropriate for universities and similar establishments to undertake to aid the pressure vessel industry;

(ii) the Minister for Education and Science ensures such information be used by SRC in taking steps to invite and to encourage appropriate basic research;

(iii) these actions be carried out under the guidance of the collaborative Pressure Vessel Research Committee proposed in paragraph 9.41.

9.17 Attention must be drawn to the limited effort devoted to works trials of novel designs, such as multi-layer materials or of new materials for pressure vessel fabrication, and of analogous work on pressure vessel components. There also appears to be only limited work in development of equipment for non-destructive testing.

Application of results

9.18 The research survey indicated that much of the R.& D work done by the industrial organisations had been applied in some way. The pressure vessel fabricators used their R & D work to change fabrication procedures to give better quality and in some cases better economy, or used it to allow the company to enter a new field with a new material or technique. In some cases it has been used to justify designs beyond those supported by current design standards. The steelmakers reported that their work had led to improvement in quality, optimisation of properties and the production and marketing of a number of new steels. Work by user organisations had led to modification either of operational conditions or of their general design approach. Apart from sponsored work, the Universities claimed little knowledge of applications.

9.19 Whilst it is probably true that many companies make use of R & D results obtained by other organisations, very few specific examples were given. The most important source of external R & D information quoted by several companies was the British Welding Research Association (now the Welding Institute, see Appendix N). One company mentioned extensive use of the publications of the Pressure Vessel Research Committee of the United States, but generally it would appear that work already published by the PVRC was not fully utilised and indeed was unknown to many of the people working in this field.

9.20 Only in very few cases were quantitative examples given of the financial savings provided by the application of R & D. Indeed it appeared that practically no organisation made a serious attempt to justify its level of R & D by any kind of quantitative cost/benefit balance. The justification was made that R & D work served as an effective insurance to avoid or reduce the considerable loss that could result from failures and delays; that it maintained the well-informed, qualified personnel needed for an effective trouble-shooting service; and that it ensured the company kept abreast of new processes or products.

Proposals for future work

9.21 The absence of any cost/benefit balance is paralleled by an absence of any real market research to give guidance on the lines of future R & D work likely to be of most benefit. The replies to the questionnaires highlighted many lines of possible interest, but appraisal had not been made on what gains were likely to result or what they would cost in terms of money and availability of effort and equipment. The Committee considers that better value for money would result from present levels of R & D expenditure through the use of market research.

We therefore recommend that

> a quantitative techno-economic appraisal be made as to what pressure vessel research would give the best promise of future returns; this appraisal would best be done following the survey of market needs (paragraph 4.3) and could be directed and sponsored by the proposed collaborative research organisation (paragraph 9.41).

9.22 The above recommendation should not be taken to imply that the only justification for research is towards greater efficiency of the pressure vessel industry. Failures of vessels in service, though fortunately rare, can be expensive and dangerous. Such aspects of long-term safety should also be considered in determining the direction of future pressure vessel research.

9.23 In respect of design, there is a strong demand for research work leading to economy in and rationalisation of design for flanges, nozzles and fittings.

Applications of plastic and limit analysis, coupled with techniques for design under fatigue and creep conditions, especially at positions of geometrical discontinuity or of multi-axial loading, have also been suggested as topics for further work.

9.24 Another area of common interest is that of gaining a better understanding of the significance of defects, particularly their influence on brittle fracture and, to a lesser extent, on creep and fatigue. Work on defects is proposed to provide a realistic basis for developing inspection standards of acceptance and rejection, However, the work is recognised to be costly and difficult, and a more practical approach may be to develop fabrication processes less prone to produce defects, or which at least would indicate their presence during production.

9.25 With regard to data collection, note is made of brittle fracture in thick sections and of the interaction of creep and fatigue; there is especially a lack of knowledge on the behaviour of weldments under these conditions. The Committee considers the most urgent problem on high temperature vessels is to learn more about creep ductility of welded materials. Similarly, more information is wanted on the brittle fracture properties of welded joints, as well as on the effects of composition, heat treatment and welding process on such joints. There also appears to be a need for an acceptable test to establish the brittle fracture properties of welded joints for production control purposes.

9.26 With regard to new materials, the most frequent demands are for improved quality steel and for higher strength weldable steels. Whilst the pressure vessel industry had been well served by the steel industry with regard to information on properties, the Committee notes that both sides feel a general lack of communication, for example with regard to the future needs of the users. In the long term this will be remedied by the technical liaison meetings between TIPA and BSC proposed in paragraph 8.13 and by the collaborative research organisation proposed in paragıaph 9.41. The Committee has, to permit prompt action, already informed the BSC of its view on the research needs of the pressure vessel industry.

9.27 It was emphasised earlier that development of new plate materials necessitates the parallel development of welding consumables and of ancillary components.

9.28 The replies to the research survey questionaires show a trend similar to the discussion held at the Institution of Mechanical Engineers on 10th January. 1968, which was based on a paper by Fessler and Stanley. The main difference between survey and discussion is that the research survey gives greater emphasis to problems related to welding and to the effects of defects. This results from the considerably larger sample covered in the research survey, together with an increased ratio of industrial replies to university replies. This difference emphasises the need for improved communications.

Communication and dissemination of information

9.29 One reply to the research survey commented that the efficiency of pressure vessel companies would be raised 'if information available for anything up to a century could be disseminated among some of our manufacturing companies'. This lack of dissemination was also shown by the lack of application of research results arising from other organisations and from the duplication of research work in progress.

9.30 The poor dissemination of information is part of the background leading to some of the failures and cracks which have occurred from time to time in pressure vessels. Problems that have led to trouble in one company, and whose investigation has led to the company adopting preventive measures, have frequently occurred again in different companies. This lack of communication could also occur even within one company.

9.31 The most direct way to disseminate certain types of information is by modification of standards. This requires a more regular and speedy system of modification than practised with British Standards. Other aspects can partially be covered by the proposed collaborative reasearch organisation actively arranging for the pooling of information. However, there is a need to ensure that information passes beyond the R & D personnel and so reaches the shop floor supervisors and management. This necessitates easily understood papers written with a slant towards practical applications, but such papers are currently rare. The nearest equivalents are occasional review notes in the BWRA Bulletin and interpretative reviews commissioned by PVRC. Another useful activity is the issue of design memoranda supplemented by data sheets. Speedy distribution, clear dating and frequent revision are essential to their success.

9.32 The Committee regards the dissemination of information as of great importance. An increased expenditure on dissemination of information and on furthering the application of research can have more effect than the same amount of money spent on research itself.

We therefore recommend that

(i) The Ministry of Technology, with the proposed new collaborative research organisation, takes steps to improve the dissemination and application of R & D information; these steps should include the commissioning of reviews and practical application papers for widespread circulation;

(ii) the Ministry of Technology sponsors the issue of design memoranda supplemented by data sheets covering topics of pressure vessel interest from such organisations as the Institution of Mechanical Engineers and the Welding Institute; such data sheets should be revised regularly and frequently, and should be in terms readily understood at the design and shopfloor levels.

Improved collaboration and organisation of research

9.33 Many of the comments made earlier in this chapter indicate the desirability of forming an organisation for collaborative pressure vessel research. Its purpose can be defined as the technical planning of collaborative R & D work related to pressure vessels; the provision of financial assistance for and control of such work; the preparation of recommendations on associated R & D activities in universities, research associations, material suppliers and non-destructive testing organisations etc.; the dissemination of information; and arranging for extra work and papers needed to facilitate the application of R & D.

9.34 Views on the proposed organisation were invited in the second research survey questionnaire, and of the 39 organisations that replied, 31 supported its formation, many of these giving very strong support.

9.35 Two main objections were the fears of overlap with existing organisations and of a complex and useless committee structure. Certainly the US equivalent (the PVRC) to the proposed UK organisation has a complex structure involving 200 qualified men serving on 30 committees. The PVRC has a budget of $300 000, and also has been closely involved with a US Atomic Energy Commission programme on the assessment of thick section pressure vessels for nuclear reactors, which programme is to cost about two million dollars over five years. Additional work by individual laboratories is reported to PVRC even though it is not paid for from the above budget. The PVRC has completed 100 technical projects and issued some 157 reports since 1946. These include several commissioned interpretative review papers.

9.36 It is important that any proposed organisation for collaborative research should have close liaison with the standards—writing hodies as well as with the fabricators and inspection organisations. This is needed to ensure rapid incorporation of research results into standards and practices, as well as to ensure that prompt consideration is given to requirements for research and development arising from vessel users. These considerations have led the Committee to conclude that the collaborative research organisation should not be based on an existing learned institution or research association. Moreover the breadth of topics to be covered ranges wider than the interests of any single existing learned institution or research association. The Committee discussed the possibility of forming a new research centre for such work but, because each aspect paralleled similar work relating to other areas of engineering, considered that it was preferable for the work to be distributed among the existing facilities, which were in the main adequate for the purpose, provided suitable arrangements were made for collaborative planning through the creation of a collaborative pressure vessel research committee.

9.37 The Committee considers that the collaborative committee should not be large and cumbersome, which might result if the members were to be regarded as representatives of differeut organisations. Instead, members of the committee should he individual experts invited from fabrication, design, materials supply, inspection and research organisations, and be able to deal with the work without reference back to their parent organisations. To get such men to spend time on this work makes it essential that they should believe the work would be valuable and that their decisions would be speedily implemented. The Committee considers such confidence would best be provided by a new organisation.

9.38 It is appreciated that the new organisation will overlap with some existing groups, such as the British Standards E/–/3/2 Committee which has been doing valuable groundwork, and this should help the new organisation to act quickly. However, no present group covered all the aspects proposed, and the Committee considers that upon creation of a new collaborative organisation all other bodies should cease their activities in this field, or arrange for them to be incorporated into the new organisation.

9.39 It is desirable that the new UK collaborative research committee should develop close working ties with the PVRC and with Commission XI of the International Institute of Welding, so as to arrange for the exchange of information on research results, methods and programme plans and, where desirable, to participate in joint experimental work. It is important that such exchanges be restricted to matters of common and basic interest so that no UK results are exchanged which could lead to commercial advantages to competitors overseas.

9.40 With regards to financing the new collaborative committee, the general view of survey replies was that finance should be in part from Government sources and in part from the pressure vessel industry. The Committee considers it would provide a legitimate method for the Government to support R & D work of direct use to the industry and thus help its competitiveness in the medium and long term.
It is important for the pressure vessel industry to feel it has a 'stake' in the work, and some form of industrial levy may be an appropriate means of providing this.

9.41 The Committee regards the formation of a collaborative research committee as necessary in its own right. However, the Committee considers that the collaborative research committee would best form part of the new Pressure Vessel Authority proposed in Chapter 13.

We therefore recommend that

(i) the Minister of Technology takes the necessary steps to form a collaborative research committee for the pressure vessel industry, preferably as part of wider reorganisation as proposed in Chapter 13;

(ii) the collaborative research committee undertakes to:

  (a) provide a forum for the joint planning and exchange of research results of commercial significance between various fabricators on a confidential basis (this could be analogous to the Joint Nuclear Power Committee involving industrial consortia, UKAEA and the generating boards),

(b) consider the research work needed to put the UK pressure vessel industry ahead on an internationally competitive basis, whilst maintaining assurance of long-term safety,

(c) advise the SRC on areas in which to encourage grants for university research and similarly other organisations sponsoring research on a national scale,

(d) arrange and finance other desirable work in university, research associations or government and industrial laboratories,

(e) arrange for the interpretation and dissemination of R & D results and for their incorporation into standards,

(f) arrange for appropriate collaboration with learned institutions and with research workers in associated areas (e.g. materials and testing) on both a national and an international basis.

General comment

9.42 In an old-established industry like pressure vessel fabrication, it cannot be expected that R & D can make startling advances immediately. It is therefore important to ensure careful planning of research expenditure. The present unplanned methods involve considerable fragmentation and duplication, and sizeable expenditures on matters which are really neither R & D projects nor projects likely to be of productive interest.
The UK pressure vessel industry appears slow to exploit research results, and several examples of this were quoted to the Committee.

9.43 There are real advantages to be gained in certain areas, such as the design of flanges and nozzles, computer-aided design, and the development of new processes. Moreover the development of more economical design standards needs experimental assessmeuts of the factors controlling failure. Another important area is that of encouraging the first large-scale application of new materials or processes. There is also the need to meet the demands of the user industries towards increasing environmental severity (e.g. temperature, pressure, size and chemical environment).

9.44 The Committee considers the proposal for a collaborative research committee made in paragraph 9.41 one of its more important recommendations. It also considers that such a collaborative committee should study at an early stage the relevant Committee of Enquiry papers on R & D aspects, particularly the detailed reports of the research survey.

We therefore recommend that

the complete reports on the Committee of Enquiry's survey of R & D in the pressure vessel industry be made available to the proposed collaborative research committee.

9.45 The Committee wishes to emphasise the importance of the need for improvement in the dissemination of results, in the application of R & D and in the advancement of industrial technology at shopfloor level. These are all areas in which the Government in the past has made less contribution through its own departments, and to which it has given less financial support, than it has to the actual execution of R & D work. The Committee considers that the stages of dissemination and application currently cause the most pressing difficulties, and Government expenditure and financial help could here be most rewarding. The Committee notes with satisfaction that the Ministry of Technology has offered financial support for work on the application of new materials and techniques in the pressure vessel industry and hopes that this encouragement will be widened and extended. A critical stage in any development programme is the 'pilot-production' stage, and the Committee considers that the Government would be taking a very effective step to help technological development if it were to offer financial incentives for pilot-scale trials or installations.

We therefore recommend that

> the Government considers, as a matter of urgent importance, what steps may be taken to give financial support and direct help to the pressure vessel industry in relation to the dissemination and application of R & D work to industrial technology and production, as discussed in paragraphs 9.32 and 9.45.

CHAPTER 10

Design: some technical aspects

Sources of information

10.1 Comments on several aspects of pressure vessel design were made in many of the replies to the general enquiry letter. Several papers on particular design aspects were submitted by outside bodies and by members of the Committee. Further information was obtained from the economic survey and from correspondence with the British Standards Institution, as well as by Committee members investigating specific points individually. The use of computers by the pressure vessel industry was raised with the Computer Division, Ministry of Technology and with the National Computing Centre. The latter body undertook a survey for the Committee and also initiated a working party to make further investigations.

The economic importance of design standards

10.2 The majority of pressure vessels are designed and manufactured according to methods and rules laid down in various published design standards (codes or specifications) most of which are issued by national organisations in individual countries. These standards vary in detail, but in general they specify the thickness of vessel wall required for given conditions, give details of nozzles, supports and other attachments, and indicate methods of fabrication and quality control procedures. Thus, the cost of a pressure vessel may depend considerably on the design standard to which it is made.

10.3 In many countries it is the general practice, or even the legal requirement, that all vessels installed in that country be made to a stated national design standard, regardless of the country of origin of such vessels. It is obviously of help in competing for exports to such countries that UK designers and fabricators should be experienced in working to the requirements of foreign standards. This is more difficult where there are marked differences between the UK and the foreign design standards, especially if the former are more conservative. A designer accustomed to designs requiring thicker sections for given conditions is unlikely to produce the most economical design against a design standard permitting thinner sections. Similarly, a fabricator who habitually works to more advanced requirements or with more advanced materials is more likely to fabricate an advanced design of vessel efficiently and without trouble. It is also necessary to have inspectors experienced with working on such designs.

10.4 These arguments emphasise that the contents of UK pressure vessel design standards can affect the competitiveness of our industry in the export market. Similar arguments apply to the import of pressure vessels into the UK. The important effect of the national design standard in relation to competition with foreign manufacturers is more obvious when a purchaser permits the vessel to be made to any design standard. In such cases, a fabricator is likely to quote for a design based on his usual practice so that a conservative national standard will lead to higher prices. An example of this is given in the economic survey (Appendix F; Annex D). The Committee considers it essential that the UK should maintain, by regular and speedy revisions, national pressure vessel design standards that are at least as advanced as those in other countries. This will not be achieved by awaiting developments in ISO Recommendations.

We therefore recommend that

> UK design standards be provided for the different aspects of importance to the pressure vessel industry and that such standards should at least be generally no more restrictive than those found acceptable in competing countries; this will necessitate frequent, regular and speedy revisions which can be achieved by the arrangements proposed in Chapter 13.

Comparison of UK and foreign design standards

10.5 Some characteristics of the national pressure vessel design standards of several countries are summarised in Table 5. Important differences are apparent in the methods of establishing the design stress which in turn controls the wall thickness. At temperatures below the creep range, the design stress is usually based on either the minimum ultimate strength of the material measured in the tension test (R_t) or the tensile yield or 0·2% proof stress (E_t). The specified values of material property are divided by an arbitrary number (commonly called the 'factor of safety' but more correctly the 'factor of ignorance' and hereafter called the design factor) to give the permitted design stress. Obviously the lower the design factor, the thinner the pressure vessel wall, so that design standards using low design factors can be regarded as the more progressive. Table 5 shows the conservative nature of BS 1500 and ASME Section VIII for temperatures below the creep range, but also indicates that BS 1515 is considerably more progressive.

10.6 The relative value of the design factors applied to R_t and E_t also determine which property controls the design stress for a particular steel under given conditions. Table 6 gives examples of the design stresses for different types of steel according to different standards. This emphasises that BS 1500 gives the lowest design stress in every case, with ASME Section VIII only slightly higher. For the long-established, low strength constructional steels BS 1515 and TUV lead to identical design stresses and give a considerable advance over BS 1500, with a reduction in thickness and of material cost by about 40%.

10.7 The position is different with the higher strength steels, for which the TUV design standard permits considerably higher stresses than does BS 1515. This arises from the requirement in BS 1515 that the design stress shall not exceed $R_t/2{\cdot}35$. Developments in steels produce greater improvements in yield strength than in tensile strength, so that the design stresses for such higher strength steels in BS 1515 become controlled by the tensile strength requirement rather than by the yield strength requirement. The Committee understands that, in some cases, TUV may also apply a requirement based on tensile strength, but even so where this is based on $R_t/2{\cdot}0$ it allows considerably higher stress levels than does BS 1515.

Table 6. Some examples of design stresses for various steels according to different design standards

The controlling room temperature design stress in each standard is underlined. The highest permitted stresses of all standards are double underlined. Further examples are given in Appendix F (Annex D). The values are only approximate and do not include the thickness correction term.

R_{20} is the minimum UTS for the steel at 20°C.
E_{20} is the minimum YS (or 0·2% PS) at 20°C.

Steel	Approximate Stress (tons/in²) relevant to indicated requirements						
	ASME VIII		BS 1500	BS 1515		TUV	
	$R_{20}/4$	$E_{20}/1{\cdot}6$	$R_{20}/4$, Weld Factor 0·95	$R_{20}/2{\cdot}35$	$E_{20}/1{\cdot}5$	$R_{20}/2$*	$E_{20}/1{\cdot}5$
Long established low strength steel e.g. BS 1501–151/26B	$\underline{6{\cdot}5}$	9·3	$\underline{6{\cdot}2}$	11·1	$\underline{\underline{9{\cdot}9}}$	13·0	$\underline{\underline{9{\cdot}9}}$
Low alloy higher strength steel e.g. Ducol W30	$\underline{9{\cdot}5}$	18·7	$\underline{9{\cdot}0}$	$\underline{16{\cdot}2}$	20·0	19·0	$\underline{\underline{20{\cdot}0}}$
Quenched and tempered steel e.g. Loyeon QT	$\underline{11{\cdot}7}$	26·3	$\underline{11{\cdot}1}$	$\underline{20{\cdot}0}$	28·0	23·5	$\underline{\underline{28{\cdot}0}}$

* The question of the calculation of R_{20} with a design or safety factor of $S = 2{\cdot}0$ has been discussed in the German literature in conjunction with high strength steel, but these discussions had yet to result in its introduction as a general requirement.

10.8 The TUV design standard gives considerably greater encouragement to the use of higher yield strength steels than do other standards. The TUV standard would allow a vessel, built of a higher-strength steel, to have a wall thickness only about 50% that of a vessel built of low-strength structural steel for the same purpose. For BS 1500 and for ASME Section VIII, the stronger steel would have to be about 70% of the thickness of the low strength steel, and for BS 1515 over 60%. This not only affects the amount of steel used but also the weight of the vessel and the associated handling costs during fabrication and transport. This last factor may even determine the ability of a fabricator to make a large vessel due to limitations on lifting and carrying capacity (see Appendices F and J).

10.9 An even greater tendency for the TUV design standard to be the most favourable is shown for the quenched and tempered steels. A similar position is found for austenitic steels, which are covered by BS 1515 Part II (publication date: 1968). This includes the restrictive requirement that the design stress shall not exceed $R_{20}/2\cdot5$ so that recent developments in higher proof-strength austenitic steels will be favoured much more by the TUV design standard than by BS 1515 Part II. For example, the warm-worked austenitic steels show increases in proof strength from 13 to 25 tons/in^2 whilst the tensile strength is only increased from 40 to 43 tons/in^2. This means that the proposed tensile strength requirement would lead to virtually no saving of weight compared to conventional austenitic steels, whilst the saving of weight using the thickness defined by $E_t/1\cdot5$ would be over 50%. In view of the need to encourage the UK pressure vessel industry to develop its use of more advanced materials, the Committee concludes that the need for such requirements must be urgently reconsidered.

We therefore recommend that

> the requirements in BS 1515 Part I and Part II, that the design stress should not exceed $R_{20}/2\cdot35$ and $R_{20}/2\cdot5$ respectively, be reconsidered forthwith, taking note of the arguments presented in paragraphs 10.5–10.9 and 10.26–10.28; this could be done by one of the Committees proposed in Chapter 13.

10.10 Table 5 also draws attention to the methods used in different countries for the acceptance of new steels. Until 1967 no procedure existed for this in the UK and even up to September, 1968 no detailed procedures and requirements had been published.

We therefore recommend that

> the procedures and requirements for the acceptance of a non-standard steel be quickly established and published; this could be done by one of the Committees discussed in Chapter 13.

10.11 With regard to scope, BS 1515 (Part I) 1967 covers only ferritic steels, in contrast with the TUV design standards. There were comments in several submissions to the Committee stressing the urgency of the need for the issue of Part II (Austenitic Stainless Steels) and in other submissions asking for extension of BS 1515 to cover aluminium and copper and their alloys, and to cover fibre glass and clad steels. With regard to the range of applications, the BS 1515 (1967) covered none of the following: thick-walled vessels for very high pressures, multi-layered vessels, and multi-walled vessels.

10.12 Many of the comments stressed the marked step forward that had been made by BS 1515 and argued that BS 1500 should now be discontinued, as the presence of two such design standards was an unnecessary complication. The BS 1515 is regarded internationally as being of a high technical level, but it does not enter into sufficient detail in some design aspects. The ASME standards give more details of their technical background and have more detailed treatments of fatigue, of vessels for low temperature, of the effect of local loads, of thermal and of discontinuity stresses, and of stress concentrations.

10.13 Turning to pressure vessel details, various submissions to the Committee criticised BS 1515 with respect to flange design, flat closures, gaskets and jointing, drawing attention to the lighter designs resulting through use of the ASME design standard and of a design method defined by the American Wellhead Association. It was also argued that even BS 1515 was more conservative than ASME with regard to dished ends, and more conservative than other standards on feed-heater tube plates and on compensations for nozzles and openings. The attention of the Committee was drawn to the differences in requirements for compensation at openings between BS 1515 and BS 3915, the latter design standard being preferred. Reconsideration of all of these design aspects was suggested as well as of the amount of welding required for fillet and nozzle attachments and of the distance between such welds, of bursting discs and of closures with large diameter bolts. The Committee considers that many of these cases would be settled quickly if a UK standing committee existed to which such cases could be put.

We therefore recommend that

> a procedure be provided for speedy action on individual cases or appeals similar to the 'Code Case' procedure of ASME, a suitable mechanism is discussed in Chapter 12.

10.14 The implied basis of many of the comments received by the Committee is that design factors should be based on satisfactory experience. Thus, if there is no evidence that the use of thinner sections has led to increased incidence of failure, then the thinner and more economical designs should be adopted in the UK. The Committee supports this view, which forms the basis of the recommendation in paragraph 10.4. Furthermore the Committee considers that where there is technical evidence, with experimental substantiation, to the effect that more economical design features would also be satisfactory in service, then the need arises for a less conservative approach to be adopted towards the introduction of such features in the national design standards.

Minimum property levels

10.15 The Committee believes that the argument in paragraph 10.14 should also be applied to the problem arising when extensive testing of a previously used material reveals that the real level of a particular property is lower than that which had previously been used. This situation had arisen in the case of several low alloy steels, where the considerable amount of data arising from the British Steelmakers Creep Committee had led the BSCC to propose minimum property levels considerably lower (by about 10%) than those guaranteed by German steelmakers for steels of analogous composition. It is illogical, and certainly it would be uncommercial, to define lower design stresses in the UK as a result of this additional data, since there is no evidence that the failure rate in Germany is any higher than in the UK for similar steels. On this basis it is to be expected that confirmation of lower property levels, associated with long and satisfactory previous experience of particular design stresses, should lead to reduction in the design factor, rather than to reduction in the permissible design stress.

10.16 It can be argued that the design factor allows for many unknowns. It can also be argued that the evidence that a lower design factor had been used with safety for one steel is not sufficient to justify the general lowering of the design factor. Even so, it would be appropriate to show unchanged design stresses for these steels, with the more recently determined minimum property levels, even if these two statements were incompatible with the usual value of design factor. The problem is not likely to be a continuing one since in future there will be more widespread testing of newly-developed steels by standardised techniques. The exception of some existing materials from the use of a particular design factor should not cause concern, as the design factor is a matter of compromise.

10.17 The Committee recognises that the particular approach made in paragraph 10.15 may not be accepted by ISO. The problem is mainly a commercial one, and the Committee considers it to be essential that no reduction in design stresses be accepted for these particular cases.

We therefore recommend that

> the UK delegates to the appropriate ISO Committees be informed of the opinions of the Committee of Enquiry as expressed in paragraphs 10.15–10.17.

The need for a rational basis for design

10.18 The previous paragraphs have emphasised the 'actuarial' basis of existing design standard rules. This leads to difficulty in justifying the use of particular design factors, or even in deciding what are to be the controlling properties. As a result it is difficult to answer objections towards altering existing rules (such as those in BS 1515) which produce a changeover from a design stress based on yield strength to one based on tensile strength when the material used is one with a yield strength/tensile strength ratio of more than 0·64 (see paragraph 10.8). These problems are more pronounced with the use of advanced materials and with engineering developments towards the more efficient use of materials. The Committee considers that the further development of design rules will require a rational approach involving the consideration of each failure contingency to which a vessel is likely to be subjected during its life, and the assessment of the conditions necessary to avoid the relevant type of failure. This type of approach has already been outlined in the more sophisticated standard applied to nuclear reactor steel pressure vessels (BS 3915) and in forged vessels for working pressures of a kilobar or more, and has been the basis of considerable work by Commission XI of the International Institute of Welding.

10.19 The Committee did not itself undertake such a detailed reappraisal, because of its commitment to cover a wide range of topics and to report within a reasonable time. The Committee can, however, provide some indication of the directions which such a rational approach may be expected to take.

10.20 The failure conditions to be considered are those leading to excessive deformation, fracture or leakage. The first can occur as a result of instantaneous plastic deformation or from time-dependent creep. The second occurs when a notch or defect is produced large enough to lead to the unstable growth of a crack under the action of the applied stress. Such failures can arise by brittle fracture from relatively small defects or even from stress-concentrations due to poor design, the tolerance for such defects increasing with increase of the fracture toughness of the material. Larger defects may grow during service as a result of fatigue, corrosion fatigue, stress corrosion or creep rupture. These can also lead to the third failure condition of leakage. The applied stress may also increase during service, for instance as a result of metal wastage by processes such as corrosion and erosion. It should be noted that simple bursting under the action of the applied pressure need not be considered, since specification against excessive plastic deformation and against brittle fracture will cover this contingency (see paragraph 10.26).

Excessive plastic deformation

10.21 The state of stress in the wall of a cylindrical pressure vessel is usually regarded as that of a hoop tensile stress with an axial stress of half this magnitude and a negligible radial stress. It is more accurate and more revealing to regard it as a triaxial tensile stress (equal in magnitude to the foregoing axial stress) superimposed on a pure shear stress. The extent of plastic deformation of the vessel is determined by this shear stress and by the shear stress/strain properties of the material.

10.22 These shear stress/strain properties can be determined with ease and accuracy by carrying out a torsion test on a solid, round test specimen. A simple torsion machine, giving the controlled strain rates necessary (particularly for high temperature testing) can be made for about £600 and would be suitable for less-skilled operators. By simple graphical treatment the results of these tests can be converted to material properties that can be used directly in assessing the behaviour of a pressure vessel, without making any assumptions as to whether deformation for that material is controlled by the maximum shear stress (the Tresca criterion) or by the sum of the squares of the principal shear stresses (the Maxwell-Mises-Hencky or octahedral shear stress or shear-strain energy criterion).

10.23 These conditions for plastic deformation cannot be predicted with the same degree of certainty from the tensile stress/strain characteristics of the material, which are moreover more difficult to determine. For thin vessels with wall thicknesses less than 5% of the diameter there could be up to 15% saving in thickness by the use of torsion rather than tension data, because of the uncertainty as to which flow criterion is relevant. There is some evidence that this saving would more certainly arise with the higher strength steels than with simple mild steels. This particular difference will not occur, however, for a spherical vessel. Nevertheless for thick-walled, higher-pressure cylindrical vessels much higher economic penalties are paid through the use of tension rather than torsion yield data combined with unsophisticated design methods (Fig. 3).

10.24 The Committee recognises that, in view of the present long-established position, it would be unrealistic to recommend dropping the use of tension

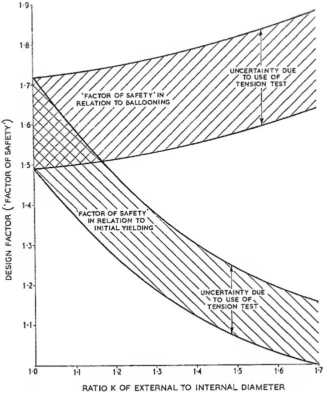

FIG. 3. Reduction in 'safety factor' in relation to initial yielding as the ratio (external/internal) diameter increases

yield data for pressure vessel design in favour of torsion data. However, it is important to recognise that the present basis of design is incorrect, and that the trend towards the use of vessels with higher thickness/diameter ratios and of vessels fabricated from low alloy steels makes it more desirable to use torsion data in the future. For instance, the use of torsion data is certainly preferable when dealing with cylindrical vessels for very high pressures, especially where partial overstrain (autofrettage) becomes desirable. The Committee suggests that a permissive approach be adopted by introducing into design standards the option to design on torsion data if so desired.

10.25 The relevant condition for failure is the pressure p_b at which widespread yield or 'ballooning' occurs. This depends on the lower shear yield stress q_y by the relationship

$$p_b = 2\, q_y ln(k)$$

where k is the ratio of the external diameter to the bore. The Committee considers that it should be permissive to use either the BS 1515 approximate mean-diameter formula or the formula

$$p = 2\, q\ ln(k)$$

where p is the design pressure, and q (by analogy with BS 1515, Table 2) is $q_y/1{\cdot}5$. The comments relating to the use of both the mean-diameter and the logarithmic formula refer to thin-walled cylinders. For thicker vessels with $1{\cdot}25 < k < 2{\cdot}0$ the logarithmic formula is preferred; while for very thick vessels with $k > 2{\cdot}0$ it is preferable to treat each case individually than to use the above formulae.

We therefore recommend that

(i) the use of torsion data for pressure vessel design be encouraged by introducing an option permitting its use into the appropriate standards as soon as possible;

(ii) an option be introduced allowing the design to be based on use of the logarithmic formula (see text of paragraph 10.25):

$$p = 2\, q_y\ ln(k)/1{\cdot}5$$

Yield/Ultimate strength requirements

10.26 It is seen that prevention of excessive deformation depends on yield properties and not on ultimate tensile strength. The tensile strength does not give an accurate value for the ultimate bursting pressure of a cylindrical vessel, especially where this is thick-walled. Moreover the Committee considers it unnecessary to introduce the criteria of ultimate bursting pressure into the design requirements. Under normal conditions the requirement for prevention of excessive deformation or fast fracture will be sufficient to guard against ultimate bursting. The latter could only occur at a pressure so much above the normal working pressure that it should be avoided by pressure-limiting protective devices, and would occur in any event in the type of runaway increase of pressure against which no strength requirements could act as safeguard. The normal requirements for control of operation should provide satisfactory protection against this contingency. There is thus no direct relevance in including a design requirement based on the ultimate tensile strength.

10.27 Advocates of the ultimate tensile strength requirement have suggested that it gives protection against fatigue failure. The Committee considers there is little relationship between the ultimate tensile strength of a material and its high-strain fatigue properties or the fatigue properties of welded joints. It is preferable to protect against fatigue failure by direct consideration of fatigue properties. Other arguments are that provision of an additional requirement based on the ultimate tensile strength avoids the problems resulting from low ductility which sometimes are associated with materials of high 'yield strength/ultimate tensile strength' ratios, and that it ensures adequate work-hardening capacity in the material. Both of these problems relate to the behaviour of stress concentrations such as defects, and proper consideration of fracture toughness requirements provides a more direct protection.

10.28 The detrimental effects of the present BS 1515 requirement based on ultimate tensile strength/2·35 have been emphasised in paragraphs 10.5–10.9. The Committee can see no logical basis for retaining this requirement and has already recommended its reconsideration (paragraph 10.9). This will necessitate detailed reconsideration of the fatigue, the ductility and the fracture toughness requirements, and of the effect of service conditions on the properties of materials and particularly for new materials.

Fast fracture and notch-toughness requirements

10.29 The use of design conditions which prevent excessive deformation will also prevent failure of a perfect cylindrical vessel. However, practical pressure vessels will contain stress concentrations, both those which are not avoided in design and those introduced accidentally in the form of defects. Moreover defects can arise or be extended by creep, corrosion and fatigue processes. This makes it necessary to consider the possibility of an extensive crack occurring from such a defect at a stress below that providing protection against excessive deformation. For any given material and environmental condition, there is a critical value of the stress applied in a direction normal to a crack, or similar stress concentration, which will cause a crack to extend in an unstable manner. This fracture stress decreases both with increase in size and severity of the defect, and with a decrease in the fracture toughness (e.g. notch-toughness) of the material. Brittle fracture in steels is an example of particular importance of this type of behaviour.

10.30 The Committee considers that the specification of the required notch toughness of materials is an important part of any design standard. Ideally the specification should ensure that failure by unstable cracking will not occur at the permitted stress levels from defects of the maximum size which may occur in the finished structure. This ideal cannot be achieved in practice since the maximum size of possible defect cannot be predicted, so that specification becomes one of engineering judgement. Indeed it may be that for many vessels, the likely range of material fracture-toughness, and the likely maximum defect size which would remain in the finished structure occurring in practice, is such that it is not necessary to require the testing of the material for fracture-toughness. It is preferable for this position to be arrived at as a conscious judgment rather than by a tacit assumption as is commonly the existing practice.

10.31 It is possible to protect some structures against this contingency by arranging for the material to be so tough, that it will arrest any crack starting in a non-typical area of high local stress or of locally brittle material. Experiment has shown that this crack-arrest approach cannot be used for many types of pressure vessel, although it may reduce the extent of damage resulting from cracks occurring during fabrication.

10.32 In the past, the specification of the required fracture-toughness has been based largely on the level of Charpy V-notch energy associated with the limited experience of failures. However, the problem of fast fracture becomes more acute with increase in plate thickness and with increase in applied stress arising, for example, from the use of a material of higher yield strength. It is these aspects that make difficult the extrapolation of existing satisfactory experience to larger and thicker vessels in alloy steels. A possible basis for extrapolation would be to carry out crack-initiation tests on full-thickness, wide welded plates and to associate the results of such tests with those on smaller test pieces. This should allow the specification of minimum notch toughness requirements that would vary with: the type of steel; the maximum section thickness; the effects of fabrication such as those that occur near the weldment; the question of whether thermal stress relief had or had not been done after welding; the possibility of dynamic loading; and the lowest temperature at which the structure would be stressed.

10.33 The Committee considers that BS 1515 should be more specific with regard to requirements for avoiding fast fracture.

We therefore recommend that

(i) the requirements of BS 1515 with regard to fracture toughness be reconsidered, taking note of the comments in paragraphs 10.29–10.33;

(ii) any further experimental work needed to provide this rational basis be initiated and sponsored by the Ministry of Technology, through the proposed Pressure Vessel Research Collaborative Committee;

(iii) these actions be supervised by one of the Committees discussed in Chapter 13.

Fatigue

10.34 A rational approach to fatigue would be associated with the concept of the growth of cracks to the size leading either to leakage or to fast fracture for the specified material under the relevant conditions. Present information is too limited to permit such a rational approach, so that existing fatigue specifications must be based largely on fatigue failure results for small polished specimens, supported by limited information from fatigue tests on thin and thick walled vessels.

10.35 Consideration of these results suggests that fatigue will not be a limiting criterion for a vessel which contains no tensile stress concentration factor greater than 3.0, and which will not receive more than 5000 major stress cycles during its life. On this basis, most of the pressure vessels built in the UK would be exempt from fatigue requirements, but the Committee would like to see such exemption defined specifically. This is not done in BS 1515, but a good model for the specification for exemption from fatigue analysis is given in detail in ASME Section III, Paragraph N–415.1.

10.36 Where a pressure vessel has to be designed for use to a large number of stress cycles, it may be necessary to reduce the permitted design stress very significantly. Experimental evidence suggests that the design stress under such circumstances may have to be only one-fifth of that applicable to a vessel exempted from fatigue requirements. The Committee considers it necessary for the fatigue requirements to be specified in detail in the UK pressure vessel standard; the ASME Section III code and its supporting document gives explanatory details that could provide a useful model for this purpose.

We therefore recommend that

(i) the requirements of BS 1515 relating to fatigue be revised and expanded, taking note of the comments in paragraphs 10.34–10.36;

(ii) this revision be supervised by one of the Committees discussed in Chapter 13.

Creep

10.37 In the case of vessels intended for service at high temperatures it is necessary to consider time-dependent creep deformation. Unlike the case for short-term properties it is not realistic to consider significant deformation by creep as a warning of imminent failure, since the time taken to reach even 2% strain is probably less than half the time required to produce a stress-rupture crack, unless the material displays creep ductility lower than that typical of present day steels.

10.38 A rational design for creep conditions would be based on the restriction of crack growths to less than the size needed to produce either leakage or fast fracture. As in the case of fatigue, absence of this type of information leads to design being based on extensive test results on small tension specimens together with very limited data from tests on tubes and vessels. A similar difficulty to that commented on in paragraphs 10.21–10.24 for short-term tests exists in the correlation between tension creep data and the behaviour of cylinders, and the Committee notes with satisfaction that some work on creep in shear is now in progress.

10.39 Any current design approach must largely be based on tension test data, and it appears from experience that the use of tension stress-rupture data in a mean-diameter formula using an appropriate design factor gives safe results, at least when the diameter ratio (k) does not exceed 2 and in the absence of major stress concentrations. It seems sensible to the Committee to vary the design factor according to the difference between the required design life and the period on which the creep-rupture stress is based, as is proposed in draft BS 806.

10.40 Existing information does not enable rational treatment of the creep behaviour at stress concentrations and nozzles. However, the theoretical and experimental work needed to establish such a treatment is likely to be long and costly. It would be appropriate in relation to its application, to make a cost-benefit study of such work as part of the action recommended in paragraph 9.21.

10.41 Experience has indicated that almost all past creep failures have been associated either with unexpectedly high temperatures or with unexpectedly low ductilities. The latter effect has sometimes resulted from ductilities lower, after long exposure times, than in short term tests, and from the reduction in creep ductility near a weld. The need for further experimental work on the stress rupture ductility of weldments has been indicated in paragraphs 8.27, 8.34 and 9.25.

10.42 The Committee recognises the difficulty of the problem of design in the creep range, especially for vessels of complex geometry and subjected to fluctuating stress and temperature. Design guidance is, however, necessary even if it must be somewhat arbitrary in origin.

We therefore recommend that

(i) the creep design requirements, to be included in a revised BS 1515 to cover vessels operating in the creep range, be based (for the present) on tensile stress-rupture data with a design factor dependent on the required design life; an objective should be the definition of requirements for minimum long-term ductility with respect to all materials including weldments;

(ii) the need for further theoretical and experimental work on creep criteria be determined using cost-benefit analysis, and appropriate action be taken;

(iii) the above recommendations be supervised by one of the Committees described in Chapter 13.

Other design contingencies

10.43 Other contingencies not discussed in this Report, but which must be covered in a rational design approach, are those resulting from corrosion and erosion and those associated with instabilities of various kinds. Mention must also be made of the relationship of permissible stress concentration factors, of the shakedown limit and of limit analysis to design creteria. The possibility of standardising various design details such as flanges, covers, branches, nozzles, supports, man-holes, end details and columns should be considered. Various comments were made to the Committee suggesting that the requirements of the proof pressure test should be reconsidered, especially for large-diameter low-pressure vessels and for vessels destined for use at high temperatures and/or very high pressures.

10.44 However important these design details may be, a major difficulty is the large number (over twenty) of existing standards, codes and specifications, with overlapping and differing requirements. To these may be added the numerous specifications of customers, of inspection authorities and also public sector organisations. The Committee considers this situation to be inefficient and would welcome a single master standard for pressure-containing parts, covering different types of vessel on the lines recently developed by the BSI/E/–/3 Committee. This would render many specifications in both the public and the private sectors unnecessary. Where, because of special circumstances, a separate specification is necessary it should be generally in line with, and refer back to, the master standard. The master standard should be written in terms of material properties rather than by reference to specific materials, and it should be supported by covering technical papers providing introductory, explanatory and background information, including the procedure for accepting new materials. The Committee also considers: that the drafting of the UK master standard should not await further ISO recommendations; that the master standard should receive regular and frequent revisions; and that 'code-case' and tentative specification procedures should be adopted to enable the rapid introduction of new techniques.

We therefore recommend that

(i) UK master standard for pressure parts covering design, manufacturing procedures and inspection requirements be prepared as speedily as possible;

(ii) in preparing such a standard, note be taken of all the points made in Chapter 10 on design, in Chapter 7 on fabrication, in Chapter 11 on inspection, in relevant papers submitted to the Committee of Enquiry, and in the excellent groundwork of the E/–/3 Committees of BSI;

(iii) on completion of the master standard, all existing BS for pressure parts be withdrawn, and the minimum number of revised standards be issued, each in line with and referring to this standard;

(iv) the Government prevents its own departments and the public authorities from issuing private specifications and invites other bodies to drop their private specifications following the promulgation of a UK master standard;

(v) for speedy adoption of new designs, materials and fabrication methods, and to provide the necessary flexibility, 'code-case' and 'tentative specification' systems be adopted;

(vi) provision be made for regular, frequent and speedy revision;

(vii) the master standard be prepared by the procedures discussed in Chapter 13.

Computer studies

10.45 Following comments made to the Committee on various aspects of the use of computers in design, the Committee invited the National Computing Centre (NCC) to form a Working Party to produce a detailed review of computer applications in the pressure vessel industry; to ascertain the desirability of increased computer use and to indicate profitable directions for development; and to propose methods for co-ordinating computer efforts within the industry. The Working Party consulted with the 'Committee on Computer-Aided Design' of the Ministry of Technology. The interim report of the NCC Working Party forms Appendix O.

10.46 The Working Party recommends the encouragement of inter-company co-operation and interchange of existing programmes; the programming of appropriate areas of design standards, of material selection and of costing; and the invitation to all organisations to submit relevant programmes to NCC, which could act as distributor for these and the previously mentioned programmes. The Working Party also recommends that discussions should be held with standards-writing bodies to ensure that future standards facilitate the greater use of computer techniques; the Working Party would also like to see short courses to acquaint design and managerial staff on the possible uses of computers and on the contribution they can make to the industry.

10.47 The Committee of Enquiry supports the above general recommendations but considers they need to be made more specific and detailed.

We therefore recommend that

(i) the National Computing Centre be invited to continue to hold meetings of the Working Party on Technical Computer Applications to the Pressure Vessel Industry, with a view to detailing their recommendations as soon as possible, to proposing methods for putting their recommendations into effect and towards indicating the cost and effort required;

(ii) the Working Party should report on its findings to the Minister of Technology or to the appropriate Committees discussed in Chapter 13, so that appropriate action may be taken.

CHAPTER 11

Inspection and associated topics

Sources of information

11.1 Many of those replying to the initial enquiry letter commented on various aspects of inspection. These comments were supplemented by papers submitted to the Committee. A review of the inspection organisations in other countries and in other engineering industries in this country was initiated by staff of Standards Division, Ministry of Technology. With this background a Sub-Committee on Inspection of the Committee of Enquiry drafted proposals for changes in the organisation of inspection in the pressure vessel industry; these early proposals were circulated to various interested parties and further comment received in reply. The sub-committee met senior representatives of some UK inspection organisations and discussed possible changes in detail. The present chapter takes note of the extensive comment, criticism and alternative proposals that have been made at various stages of these discussions.

Background

11.2 Inspection of pressure vessels began in the early 19th century following a number of explosions and failures. A group of engineers, the Manchester Steam Users Association undertook to examine plant to consider whether it was fit for service, and eventually backed their judgement by payment in the event of failure. Thus arose an association between inspection and engineering insurance which continues to the present day. However, the contractual links between inspection and insurance relate to in-service inspection on behalf of the pressure vessel user, and not to inspection during manufacture which is of main interest to the Committee of Enquiry. The premiums for user insurance are not tied to pre-purchase inspection requirements, and whilst several inspection organisations have insurance origins their divisions for inspection during manufacture are said to be administratively separate from those for insurance.

11.3 In addition to inspection organisations, inspection during manufacture is carried out by many others, including purchasers (both public authorities and private companies), contractors, consultants and fabricators. This has led to multiplicity both of inspection and of inspection requirements, and these have been major points of comment to the Committee. Whilst this problem is common to many aspects of engineering, and whilst it was not a major cause of the price differentials between many of the 1965–6 quotations for pressure vessels from the UK on the one hand and from some foreign countries on the other; it is nevertheless a problem requiring urgent attention as it can and does cause delays.

11.4 The need for a satisfactory inspection service is recognised by all parties. One objective is to decrease the hazard to personnel. Another major reason for inspection is to save money, by reducing the risk of expensive failures during manufacture, testing or use. The viewpoints of the materials suppliers, of fabricators and designers, of contractors, purchasers and users and of the insurance and inspection organisations all differ, and this is a prime cause of the present multiplicity of inspection. A satisfactory inspection service must recognise these different interests and obtain a solution that satisfies the various needs of these organisations.

11.5 It must be emphasised that the duties of a complete inspection service go considerably beyond execution of mechanical tests and of non-destructive examination. Such a service can be required both at and before the tender stage and during the contract work: to approve designs and drawings; to approve the selection of materials, of fabrication procedures, and their specification and methods of assessment; to carry out weld procedures and production tests and approval of welders; to inspect materials; to carry out stage-by-stage inspection during fabrication and to ensure satisfactory procedural control; to witness or carry out at various stages of fabrication destructive tests and non-destructive examination as well as the proof-pressure tests and final acceptance tests.

Present problems

11.6 Most of the problems reported to the Committee arose from the current multiplicity of inspection organisations and the subjective nature of the present inspection standards. Not only may there be different inspectors for different jobs in the same shop, but a single job may be visited by different inspectors (frequently two and occasionally as many as four) representing different interests such as the contractor and the user. There are delays in waiting for inspectors, each of whom has to be received and escorted, and there can be further delays through inspectors reporting back to their head offices. This state of affairs has happened both at the materials manufacturers and at the vessel fabricators, although some reduction in the delays at steel mills should result from a recent agreement between the two major inspection organisations to rationalise and to accept each others steel mill certificates.

11.7 Not infrequently there is disagreement between inspectors from different organisations concerning the same product. There can even be disagreement between inspectors of the same organisation; for example, a component already accepted for despatch from one site may be rejected on receipt at another. These differences arise in part from the subjective nature of much of inspection, the standard (or specification) relying in general on individual inspectors to decide what is or is not acceptable on the basis of their own experiences and skills. The differences between inspectors can thus be caused by differences between their individual experiences and skills, and there is no common requirement, independent assessment, or certification of individual inspectors. These differences can lead to prolonged arguments with consequent delays. In most cases there is no appeal against the judgement of an inspector. The Committee notes that all of these facets can lead to delays and to extra cost and can cause considerable irritation and ill-feeling amongst the parties involved.

Comparison with other inspection systems

11.8 The systems adopted for inspection services in other countries are summarised in Appendix P. They vary considerably and the Committee has been unable to select any one as an ideal on which to model its recommendations. The German TUV system is of particular interest, being run by independent enterprise with state approval. The German system practised approval of certain fabricators for particular aspects and exempted them from some external inspection. The system is reported, however, to suffer from rigidity of approach and from conservatism.

11.9 An inspection organisation of considerable interest as a model is the Aeronautical Inspection Directorate (AID) which has been in existence for over 50 years. This organisation is planned to provide an integrated inspection service under unified direction within the Ministry of Technology. It permits delegation of inspection from one constituent inspectorate to another to obviate overlap. It provides regional services and inspectors resident on particular sites to undertake all the relevant inspection in their defined regions. It also operates an 'approved company' system by which a company having its own independent inspection department, fulfilling stated requirements, is authorised to make its own inspections under the supervision of resident or visiting AID staff.

11.10 Another organisation with features of interest is the new British approvals service for testing electrical equipment in flamable atmospheres (BASEEFA). This is the responsibility of the Ministry of Technology and is guided by an appointed Advisory Council, and it will authorise and appoint testing stations on whose reports BASEEFA certificates can be based. Somewhat similar arrangements apply to the British Calibration Service for scientific instruments, the approved laboratories being authenticated for quality of staff, procedure and validity of calibration standards.

11.11 The inspection of gas cylinders is controlled by the Home Office. The requirements for cylinders complying with Exemption Order 16 are mandatory and gas cylinders may only be manufactured and inspected by manufacturers and independent inspection organisations approved by the Minister of State, Home Office. On being asked by a manufacturer for such approval, the Home Office takes advice from other bodies such as other makers, users, inspection organisations and government departments. This is followed by destructive tests of sample cylinders of each relevant type. The approval of inspection organisations follows a similar pattern; the Home Office keeps a Register of Approved Manufacturers and another of Approved Inspection Organisations. A Pressure Containers Advisory Sub-Committee has been proposed which will deal with special cases and also will provide a 'code-case' system and a system for up-dating standards. A somewhat similar system of type-testing supported by Authorised Inspectorates with appointed examiners is proposed for serially-made, type-tested, welded air receivers by the European Committee for the Co-ordination of Standards (CEN/WG/42).

The disadvantages of a single nationalised pressure vessel inspectorate

11.12 As a means of obtaining further opinion, the Sub-Committee on Inspection asked 28 organisations to comment on a proposal that all aspects of pressure vessel inspection should be transferred to a single National Inspection Authority (NIA) which would have in its employ all of the relevant inspectors, and which would be responsible to the Minister of Technology. The replies, which are summarised in Appendix Q, gave considerable support to the view that it was desirable to provide some system of state-certification of individual inspectors as well as a nationally co-ordinated scheme for pressure vessel inspection. However, the majority of respondents considered that this co-ordination would better be done by a single 'umbrella' authority which did not employ its own inspectors, but which authorised those in certain existing inspection organisations. These alternative views arose because difficulties had been seen with the NIA as originally proposed with regard to the legal and financial responsibilities following any failures of inspected vessels, and the allied fear that NIA employees would thus take a restrictive line regardless of cost. It was commented that such an organisation could prove to be inflexible and conservative and would suffer from lack of competition. Continental experience was quoted to support these views. Another major criticism was that, because the NIA could only be formed by taking skilled men from existing organisations, much of the considerable experience of existing organisations would be lost to the pressure vessel industry. This would especially be the case if the existing organisations remained to carry out engineering inspections other than on pressure vessels. Other problems, including difficulties in financing the NIA, were also predicted.

Development of an alternative system

11.13 After considerable discussion the Committee decided, on the grounds of complication and cost, against recommending a system based on the formation of a single nationalised organisation. The Committee preferred to seek a system which would make use of certain existing inspection services, co-ordinated and simplified, so reducing the physical and organisational upheaval of skilled and experienced personnel. The principal objectives of this reorganisation would be: to avoid duplication of inspection; to obtain reciprocal acceptance of inspection certification both nationally and internationally; to obtain common standards between inspectors; to make suitable arrangements for the training of inspectors; and to ensure that innovation and changes in technology were quickly evaluated with a view to their use.

11.14 Towards this end the Committee considered a number of schemes, and also held discussions with senior representatives of Lloyds' Registry of Shipping (Land Division), the Associated Offices Technical Committee and the British Insurance Association, which are the organisations that currently cover the majority of the inspection of pressure vessels during manufacture. The representatives expressed a willingness to work together to rationalise their inspection services and to eliminate duplication.

11.15 The organisations made a number of positive proposals. One was that inspection reports should be interchangeable and that those from any one of these organiations should be accepted by the others. This would obviate the need for separate inspection arrangements leading to multiplicity of inspectors in both steelworks and fabricators' works. They would then arrange for the appropriate number of inspectors to cover each important works to give an essentially residential service. They agreed with the concept that the individual inspection bodies should be licensed by a central Government-approved committee, and put forward views on the organisation of this committee particularly stressing the need for simplicity and economy. They suggested that the requirements for licensing should be modelled on those given in Appendix III of the EEC document on the certification of pressure plant (see Appendix P), and they considered that the number of such licensed inspection bodies should be strictly limited. They agreed that the manufacturing inspection activities would be entirely separated from insurance activities and from in-service inspection. However, any licensed inspection would be accepted as approving a vessel for insurance.

11.16 The Committee welcomed these proposals, and noted that a variety of functions for and organisational arrangements of the central co-ordinating committee could be defined. On the one extreme it could be regarded as the national inspection authority working through the existing inspection organisations; this would lead to a dichotomy of responsibility, an elaborate administrative machine, and difficulty in costing. A simple authentication committee would have difficulty in providing adequate authority to reduce duplication of inspection and to obtain uniformity of standards. It would also be necessary to ensure that the different interests of fabricators, contractors, purchasers and users all be adequately recognised and satisfied, so that these may accept inspection services other than their own. Similarly the inspection organisation must be suitable to obtain recognition by foreign inspection organisations.

11.17 The Committee therefore proposes the formation of a national Pressure Vessel Authority (PVA). A major duty of the Authority would be the supervision of organisations that carry out inspection of pressure vessels in the UK. This Authority would report to the Minister of Technology, but it would be an independent public body authorised to take executive action. The Authority would assess, and where appropriate, approve, those inspection organisations wishing to carry out pressure vessel inspection. Each organisation so approved would then be authorised to issue PVA certificates of inspection, and to use a PVA approval stamp, in addition to some individual mark of identity. However, the PVA would not be involved in any part of the day-to-day arrangements for the inspection of vessels. This would be done, as now, by direct negotiation between purchasers, fabricators and inspection organisations; similarly all financial arrangements and technical reporting would be done direct. It would be a condition of PVA approval that all approved organisations would be expected to make mutual arrangements to reduce duplication of inspection, using each other's inspectors where this aided efficiency, and failure to co-operate in this way could lead to the removal of PVA approval. A system of appeal against particular arrangements and decisions would be provided; however, except where overruled in such an appeal, the responsibility for an individual decision would normally be that of the inspection organisation involved. Some provision for inspection to customers' requirements would have to be made to cater for advanced designs used in special circumstances.

11.18 Considering the position of the PVA in relation to legal requirements, the Committee recognises that detailed legal requirements could lead to rigidity and conservatism in pressure vessel practice. The Committee believes, however, that it is desirable for any new pressure vessel to be certified as of adequate and approved quality, that the issue of such certificates should be done only by organisations that have been approved by the PVA, and that regular reappraisals should be made of organisations approved in this way.

11.19 The Committee also recognises the potential economic advantages if fabricators were entrusted to carry out some of the inspection themselves. This particularly applies to inspection at intermediate stages of fabrication. However, it is essential to maintain user confidence that the product is properly inspected, and that acceptance decisions are not being unduly affected by commercial influences. The Committee considers that the PVA should provide a system similar to, and possibly co-ordinated with, the AID scheme, whereby fabricators having inspection divisions which demonstrably had the satisfactory organisation and skills, could receive PVA approval to carry out some inspection steps themselves. This approval would be limited to specifically stated activities and the degree and form of supervision would be defined for each case.

11.20 Another duty appropriate to the PVA would be to arrange for the certification of individual inspectors. This applies particularly to those engaged on physical examination during fabrication, and it would be necessary to cover separately different inspection techniques such as mechanical testing, radiography, ultrasonic inspection of plate, and ultrasonic inspection of welds. The certificate would indicate a standard of skill in particular aspects of pressure vessel inspection and there may be need to recognise different grades for different classes of work. The employment of PVA certified inspectors would be one condition of PVA approval that would be of special importance in considering fabricators' inspection services. It is likely that some interim arrangements would have to be made to avoid dislocation of present inspection arrangements whilst inspectors became absorbed into the approved scheme.

11.21 An associated duty would be to ensure the provision of suitable training schemes to provide an adequate flow of trained inspection personnel, and to enable existing staff to keep abreast of new developments and to maintain common standards. The PVA could arrange this through the education authorities, the industrial training boards, the Non-destructive Testing Institute and other associated organisations.

11.22 It must be emphasised that confidence in the eventual product relies as much on the adoption and control of suitable procedures throughout fabrication as it does on subsequent inspection and examination of the product. It is important that any vessel should be made by fabricators competent in the procedures needed for that particular class and type of vessel, and with the necessary qualified personnel and administrative organisation to ensure such procedures are satisfactorily used. It has been emphasised in paragraph 7.17 that these aspects become of increasing importance with the use of higher design stresses and of modern materials and techniques. The assessment and registration of the competence of fabricators on these lines could appropriately be arranged by the same organisation as that responsible for the assessment of inspection. It is expected that such assessments would be recognised by all concerned.

11.23 The proposed PVA would take part in international discussions to improve acceptance of UK inspection organisatious in different countries. As regards inspection of vessels manufactured abroad, it is not proposed that foreign inspection organisations be authorised to use the PVA stamp and certificates of approval, but to authorise inspection by selected foreign organisations as an alternative to inspection under the PVA stamp.

11.24 The Committee regards it essential that the proposed central inspection authority be linked closely with the body responsible for producing design, manufacturing and inspection standards for the pressure vessel industry, as well as with the body responsible for co-ordinating research and development. A proposal is made in Chapter 13 which would provide these close links by the creation of the Pressure Vessel Authority (PVA). However, it is recognised that these proposals may be influenced by aspects of engineering inspection of other industries and by international discussions on inspection. The Committee nevertheless regards it as very desirable that the proposals regarding the organisation of inspection in the pressure vessel industry be carried out as a matter of urgency whether the Pressure Vessel Authority is or is not charged with these wider responsibilities.

We therefore recommend that

(i) measures be taken to reduce the difficulties arising from the multiplicity of inspection organisations in the pressure vessel industry;

(ii) the Government sets up an 'umbrella' central inspection authority that would assess and, where appropriate, approve inspection organisations, authorising them to use a common form of certification and a common stamp of approval, as discussed in paragraphs 11.17–11.18; acceptance of inspection by other approved organisations, and of planning to reduce problems of multiple inspection, would be conditions of approval;

(iii) the central inspection authority be part of a national body with wider interests, for example, the Pressure Vessel Authority discussed in Chapter 13;

(iv) the central inspection authority assess, when so requested, the inspection services of fabricators and, where appropriate, give approval for them to carry out specific inspection activities under appropriate supervision (paragraph 11.19); similarly the authority should, when so requested, assess and register the competence of fabricators to manufacture particular classes or types of pressure vessel (see paragraph 7.17, recommendations (i) to (iii));

(v) provision be made for certification of individual inspectors, indicating their competence to carry out specific inspection activities to the requirements of specific classes of pressure vessel (paragraph 11.20);

(vi) the present arrangements for training new inspectors, and for enabling existing inspectors to keep abreast of new developments and to maintain common standards, be reconsidered and appropriate action taken;

(vii) the Government requests all public sector bodies to adopt the procedure outlined in paragraph 11.24, and to employ only such fabricators, inspection organisations and inspectors that are approved by this procedure;

(viii) the Government notifies trade associations and other relevant private sector organisations of the action in paragraph 11.24 (vii) and invites them to do likewise;

(ix) the procedure indicated in paragraph 11.24 be recognised as the procedure to be adopted whenever approval of an inspection organisation, a fabricator or a 'competent person' be required by law or by a standard.

11.25 The Committee wishes to emphasise that the staff directly employed by this central inspection authority should be strictly limited to the minimum necessary to carry out the duties described above. The central authority should make full use of existing inspection organisations in obtaining evidence on which to base its initial and subsequent approval of such inspection organisations. For example, where appropriate, the staff and local organisations of AID should be used.

11.26 The provision of an effective service with minimum staff depends a great deal upon getting the right man as its full time director. He will require not only a high level of technical and organisational competence; but also the ability to demonstrate a high level of impartiality in taking account of the differing requirements of the different parties involved.

11.27 The detailed organisation of the central inspection authority depends on whether or not it would form part of the proposed PVA with its associated wider terms of reference. In any case it is proposed that an Authentication Committee should exist to establish the requirements for each type of assessment, and to determine the policies to be adopted by the full-time staff. It is necessary that the Authentication Committee reflects the various interests of the materials manufacturer, fabricator, inspector, contractor, designer and ultimate user. Nevertheless to do its task effectively it must remain small. This would not be achieved by seeking representatives from each of the large numbers of organisations that could claim an interest. The advice of such organisations and of their senior full-time staff should be sought, but members of the Authentication Committee should be appointed by the Minister in a personal capacity solely on the basis of their individual ability to contribute to the work of the Committee. This, and other related aspects, are discussed further in Chapter 13.

CHAPTER 12

The preparation, modification and application of standards

Background

12.1 The content and application of national standards can have a pronounced influence on the long-term viability of the pressure vessel industry, even though, in general, they are not major factors in determining immediate prices and deliveries. In the various contributions to the Committee of Enquiry, there is considerable praise for the final format of certain British Standards such as BS 1515 and the associated material standards, as well as favourable comparison with the situation abroad. On the other hand many criticisms were made of the slowness of preparation of new standards, of the infrequency and slowness of revision, and of the difficulty and delay in getting developments of technique, material or design incorporated into British Standards. These comments were made in the original evidence submitted to the Committee, in the economic survey, and in many of the replies to the materials survey.

12.2 Similar comments have been made in other branches of engineering, and in 1963 the Feilden Committee considered there was 'a case for another review of the BSI's method of operating as it affects design standards—a review that might be undertaken by the Institute itself rather than by an outside committee'. As a result, The Executive Committee of BSI set up, in November 1963, a special committee (the Bowlby Committee) to examine the criticisms made in the Feilden Report.

12.3 The broad conclusion of the Bowlby Committee, as endorsed by the BSI Executive Committee, was that 'The general basis of BSI's operation was sound but a greater sense of urgency. . . . (was). . . . needed. The results of research must be more quickly reflected in British Standards. Though the aim must continue to be to establish British Standards by agreement, conflicts of view should be more quickly resolved by impartial ruling and should not stand in the way of publication of British Standards. . . .'. To this end the Bowlby Committee made a number of detailed recommendations, also endorsed by the Executive Committee, which included: the use of small panels for detailed drafting; greater attention to the programming and priorities of various projects; the fixing of target dates; the encouragement of Committees and staff to plan the quick completion of individual projects rather than to keep a large number on hand, all progressing slowly; the discussion of drafts in Committees only after comment by industry; the reference of disputes to the Executive Committee; and an increase of staff responsibilities.

Comments on the present situation

12.4 The main comments and criticisms received during the present Enquiry were repetitions of points put forward by the Bowlby Committee. In view of this, the Committee of Enquiry attempted to establish from BSI how far the recommendations made in 1963 had been applied to those sections of BSI relevant to pressure vessel Standards.

12.5 With regard to target dates, BSI stated that these had in general not been used during the drafting and modification of either the various Standards related to pressure vessels and similar structures or to the associated materials Standards. It was argued by BSI that such target dates could not be fixed because the technical committees were awaiting research results or Recommendations from ISO or other bodies. There appeared to be no overall programme or plan of priorities for pressure vessel projects, and one difficulty in implementing any such plan is the variety of different industry committees involved:

MEE (Mechanical Engineering),
CHE (Chemical Engineering),
PEE (Petroleum Equipment),
NCE (Nuclear Engineering),
ISE (Iron and Steel),
WEE (Welding).

In 1966 an attempt was made to remedy this situation by transferring all the work on pressure vessels in the above six Committees to one Industry Standards Committee, but because according to BSI 'it was not possible to get unanimous agreement' this was not successful, and a co-ordinating and advisory committee (E/–/3) was formed instead. This appears to have been one occasion when an appeal to the Executive Committee could have been made, but was not. The Committee of Enquiry also understands that a prolonged dispute during the drafting of BS 1515 (Part II) for austenitic steel vessels over design stress levels was not referred to the Executive Committee. Indeed, BSI stated that 'so far it has not been considered necessary to refer any matters to the Executive Committee in the field of pressure vessels.'

12.6 With regard to BSI full-time staff, in 1963 pressure vessel work accounted for about 1.3 man-years effort divided between two senior technical officers and one technical officer. In 1966 pressure vessel work accounted for 3.4 man-years effort, divided between two senior technical officers and three technical officers. These five officers served committees of five Industry Standards Divisions, as well as spending considerable time on corresponding international work. However, BSI considered that the availability of staff did not delay pressure vessel work, this being dependent on the availability of information from outside sources. On the other hand, almost all of the general comments regarding the delay in steel Standards received by the Committee of Enquiry in the course of the materials survey stressed that, even though the relevant staff at BSI was of high quality, it was inadequate in number and was considerably overloaded. These comments also pointed out that the Bowlby proposal for the early circulation of detailed drafts had not been adopted in revising Standards for pressure vessel steels.

12.7 Another reason given for the much-criticised slowness in preparing and revising Standards was in the nature of the BSI Committees. Not only was the whole structure of Committees covering pressure vessel interests complicated and overlapping, but the individual Committees tended to be large and unwieldy. This arose because the Committees often consisted of representatives from the many different organisations that could claim an interest in pressure vessels. The operation of these Committees, on the basis of preparing drafts which had the unanimous approval of the whole Committee, lead to obvious delays and difficulties. This was intensified when representatives had to refer back to their respective organisations for further guidance; in this respect much depended on the seniority and ability of the individual representatives attending the Committees. Furthermore, the resultant drafts could be substantially biased by minorities.

12.8 The Bowlby Committee stressed this point in 1963 in recommending that 'industrial and other organisations nominating members of BSI Committees should provide representation which is authoritative and of high calibre both from the technical and commercial point of view'. The position in 1968 appeared not to have changed since this recommendation was made, and many of the criticisms received by the Committee of Enquiry reflected on the inadequate support given by industry to the BSI working Committees. To prepare good standards requires committee members with excellent knowledge and ability and such men are always heavily committed. Such men will, in the main, only devote their time and effort to standards work if they have confidence that such effort will speedily and effectively produce results.

12.9 The Committee is aware that BSI is essentially an industrial co-operative organisation and is basically under industrial control. Thus industry supports BSI, and BSI's method of operation would appear to be as much the ultimate responsibility of industry as it is the immediate responsibility of BSI senior management. It can be questioned whether representative industrial associations devoted adequate effort on drafting standards prior to the formal BSI Committee stage. Likewise it can be questioned whether BSI appreciated that it alone seemed to be satisfied with the service it gave on pressure vessels. It is true that industry gets the service from BSI for which it pays, but there is no evidence to suggest that industry would not pay more for a better organised service.

Some proposals for change

12.10 The Committee of Enquiry considers that confidence in the Standards-writing service can only be achieved by changing the present arrangements for arriving at pressure vessel Standards. This would involve separating such aspects from the several Industry Committees (MEE, CHE, PEE, NCE, ISE, and WEE) at present involved, and forming a single body to deal with Standards for the pressure equipment industry: the Pressure Vessel Standards Body. This Body would be responsible for planning and time-tabling the drafts and revisions of the appropriate Standards, and for the appointment of the chairmen of the various committees needed to carry out such work. Each working committee would be small and its membership chosen for individual expertise rather than as representatives of different organisations. Account would, of course, be taken of the advice of interested organisations in selecting the membership, which would be done by the chairman and by the supervising Body. It is expected that whilst these committees would establish the principles and broad outlines of the Standards, much of the detailed drafting would be done by professional staff. The professional staff would in part be full-time employees of the Pressure Vessel Standards Body, and in part be others seconded from industry, government establishments and research laboratories and other associations having interests allied to the particular Standard. This would require the number of full-time staff available for pressure vessel Standards work to be increased above that currently provided by BSI.

12.11 It is expected that the working committees would issue drafts for comment by industry at an early stage. The Committee of Enquiry considers that it would not be necessary for the eventual Standard to be unanimously agreed, either by the working committee or by the industry, but that it should be based on majority opinion. The final decision would be by the Pressure Vessel Standards Body. Chairmen of the working committees and the full-time staff would be expected to take speedy action to seek a ruling from this Body whenever discussions in the working committees or other industrial comment indicated marked disagreements.

12.12 The conclusion that the need for unanimity is not required is based on the recognition that Standards are not defined by absolute and basic technical principles. What they should represent is the best engineering judgment available at a particular time, this judgment being influenced by commercial and by safety considerations. This also makes it essential to provide procedures for appeal and almost continuous revision in the light of new information or altered circumstances. Suitable methods for providing this flexibility are discussed in paragraphs 12.17 to 12.19.

12.13 The Committee recognises that Standards for some materials, components, fabrication methods and inspection procedures are used not only in the pressure vessel industry but also in other branches of engineering. It is intended that the proposed Pressure Vessel Standards Body should try to co-ordinate its requirements with those of other industries, and where possible make use of existing drafting committees for those Standards of common interest. However, many of the changes relating to method of operation, membership and technical support referred to in paragraphs 12.10 to 12.12 would need to be applied to such committees if they were to achieve the necessary speed of operation. If this was not done, the Standards body may find it necessary to make its own arrangements for processing such Standards for the pressure vessel industry alone.

12.14 One possible way of making the above changes is within the framework of BSI. This would involve creation of a new Industry Committee, enlarging the permanent staff, and modifying various aspects of procedure and committee structure. In view of the international prestige and established nature of BSI, the Committee of Enquiry considered this approach carefully. However, the Committee did not regard it as a satisfactory solution. It noted the comment made in one of the submissions that whilst 'the BSI grew out of the British Engineering Standards Association, with the recent expansion of activities, there is a belief in some quarters that engineering standards are suffering. Also the internal organisation is getting so disintegrated that co-ordination is not effective and attempts to improve the situation have so far been largely abortive'. In relation to this last point, it appeared to the Committee of Enquiry that the recommendations made in 1963 to improve BSI had not been put into effect (see paragraphs 12.4 to 12.9), at least with respect to Standards relating to pressure vessels. It is essential to restore confidence in the procedures for preparing such Standards if the UK is to get the highly experienced men required to serve on working committees; this confidence is more likely to be restored by a completely new and streamlined organisation.

12.15 There are other factors suggesting that a separate organisation would be preferable. The safety requirements and legal implications associated with pressure parts put the pressure vessel industry in a special position compared with most other branches of engineering. There are obvious advantages in associating the organisation for assessment of designs and for the inspection of pressure vessels with those for preparing and modifying Standards and for supervising research and development (see paragraphs 9.41 and 11.24). The Committee considers that such an arrangement would be more likely to achieve the desired results than would changes in the methods of preparing Standards under BSI control. In order to provide continuity with existing Standards to make use of existing BSI publishing and sales organisations, and to take advantage of the international reputation of BSI, it would be appropriate for the Standards to continue to bear BS numbers and for them to be issued under the aegis of BSI.

12.16 An example of a procedure similar to that recommended by the Committee is that employed by the Swedish Pressure Vessel Commission. A somewhat similar procedure, for the issue by BSI of British Standards prepared by a different organisation, has been accepted by BSI for Standards relating to gas cylinders, which are components in many ways analogous to pressure vessels. In this case the British Standards embody detailed specifications drawn up by the Home Office, in consultation with other interests, and not agreed through the usual consensus machinery operating within the BSI's technical committee structure. In this case, no modification of the technical and inspection requirements would be permitted in any re-drafting for publication done by BSI.

We therefore recommend that

(i) the Government takes the necessary steps to replace the present BSI committee structure, for the preparation and revision of Standards relating to the pressure vessel industry, by a single supervising body (the 'Pressure Vessel Standards Body') supported by small working committees as discussed in paragraphs 12.10 to 12.12;

(ii) the Pressure Vessel Standards Body be a new organisation rather than a modification to existing BSI structure, however, the Standards so prepared should be issued under the aegis of BSI and show continuity where possible with existing BS;

(iii) the new Standards body be closely associated with arrangements for inspection and for collaboration on R & D within the pressure vessel industry; it would be appropriate for all these activities to form part of one new 'umbrella' organisation.

Revision of standards

12.17 The need to be able to modify Standards quickly to follow either changed conditions and/or new information was stressed in paragraph 12.12. It would also be valuable to have some Body to which users could appeal for interpretation of existing Standards in terms of particular cases. An extension of this principle allows such 'code-case' committees to consider the extension of Standards to cover the use of new or alternative materials, techniques and situations not already covered. Such procedures have been adopted in several countries abroad.

12.18 A suitable procedure has been detailed by the American Society of Mechanical Engineers and is described in the following quotation from the Foreword to the ASME Boiler and Pressure Vessel Code Section III (1965) Edition:

> 'The (ASME) Boiler and Pressure Vessel Committee meets regularly to consider requests for interpretations and revisions of the rules. Inquiries must be in writing and must give full particulars in order to receive consideration. Requests for interpretations which are of a routine nature may be executed by the Secretary of the Boiler and Pressure Vessel Committee without reference to a sub-committee. All other requests are first referred to the proper sub-committee for consideration and for recommendation of action by the Main Committee. The action of the Main Committee becomes effective only after confirmation by letter ballot of the Committee and approval by the Council of the Society.
>
> 'Interpretations of general interest are published in 'Mechanical Engineering' as Code Cases, and enquirers are advised of the action taken. Code revisions approved by the Committee are published in 'Mechanical Engineering' as proposed addenda to the Code to invite comments from all interested persons. After final approval by the Committee and adoption by the ASME Council, they are printed in the addenda supplements to the Code.
>
> 'Code Cases (interpretations) may be used in the construction of vessels to be stamped with the ASME Code symbol beginning with the date of their approval by the ASME Council.
>
> 'After Code revisions are approved by council they may be used beginning with the date of issuance shown on the coloured sheet addenda. Revisions become mandatory as minimum requirements six months after such date of issuance, except for boilers or pressure vessels contracted for prior to the end of the six month period.'

12.19 The Committee considers that a procedure, identical in all essentials to the ASME Code Case procedure, should be adopted in the UK. With respect to pressure vessels this could be operated within the framework of the organisation proposed in paragraph 12.16. There are however occasions when designs, procedures or materials are proposed that are so different from existing practice that they could not be covered by the Code Case procedure applied to existing Standards. In such cases it is desirable to issue tentative specifications which would be applicable where the level of knowledge and experience is insufficient to justify a Standard. Such tentative specifications would be used by agreement between the supplier and eventual purchaser, and could involve special inspection or other precautionary requirements. After a prescribed period (say 2 years) a tentative specification would be considered either for adoption as a Standard, perhaps in a modified form; or for renewal in a tentative status or for cancellation. Similarly, regular and frequent revision of Standards is also desirable.

We therefore recommend that

(i) a 'code-case' procedure (including publication of code-case proceedings) be provided for Standards relating to pressure vessels, as described in paragraph 12.18;

(ii) a procedure be adopted which allows tentative specifications to be issued covering new materials and methods;

(iii) all tentative specifications and Standards be reviewed regularly and frequently;

(iv) the above recommendations be taken into account when planning the reorganisation proposed in paragraph 12.16.

Other aspects

12.20 An important aspect to be considered is the relationship of UK Standards to ISO Recommendations. The Committee agreed that UK Standards equivalent to ISO Recommendations must be available for use in respect of export orders. Nevertheless, all experience showed that agreement on ISO Recommendations took considerable time and could well result in very conservative Standards. The issue of UK Standards should not await finalisation of the corresponding ISO Recommendations. There should always be available in the UK domestic Standards which represent the most advanced interpretation of existing knowledge, and which are not more restrictive (e.g. do not call for lower design stresses) than any similar Standard which has proved satisfactory in competing countries. The existence of an advanced national Standard can have an important influence in shaping the format, and in progressing the development of, ISO Recommendations. Indeed, this was the case with BS 1515 (Part I) which was recognised as an advanced Standard that could be used as the basis of discussion for the proposed ISO Pressure Vessel Recommendation.

12.21 The preceding paragraph must not be taken to mean that the Committee approved of a multiplicity of Standards. On the contrary it would like to see the present large number of BS covering pressure parts combined into a unified treatment involving a much smaller number of inter-related Standards (see paragraph 10.44). These Standards should be sufficiently comprehensive to obviate the need for private specifications; in this respect the Government should take a lead by encouraging the public sector to procure pressure vessels only against the BS and not to use their own specifications. Where special use made non-standard requirements unavoidable, these should be provided as the simplest possible addendum to published Standards. The use of the Code Case procedure could be of value here, even if such Cases were only of transient value.

12.22 The Committee considers this is one aspect in which the Government can with value provide considerable assistance to industry. In addition to the provision of the appropriate full-time staff, it would be appropriate to make available funds to cover the costs of part-time attached staff (some of whom could come from Government establishments) and of committee members. Provision of a suitable residential venue to enable intensive, continuous preparation of drafts should also be considered. Where development of Standards awaits experiment or demonstration, Government help in providing this could be invaluable.

12.23 It is important that Standards take note of any relevant failure experience. There is at present legislation requiring accidents leading to absences from work to be reported to the Department of Employment and Productivity, the explosions of boilers to be reported to the Board of Trade, the explosions of certain gas cylinders (which cause injury or death) to be reported to the Home Office, and the explosions of pressure vessels (whether or not injury is involved) to HM Factory Inspectorate which is responsible for arranging any investigation considered necessary. The Committee wishes to suggest that with regard to pressure parts, these reporting requirements be changed to reporting to the Pressure Vessel Standards Body. If because of wider implications than those considered by the Committee of Enquiry, this was found to be inappropriate, then these various Government organisations should be invited to inform the Pressure Vessel Standards Body of any accidents involving pressure parts, and to invite it to co-operate in any enquiry. It is also suggested that it be made obligatory for fabricators, inspectors, users or other parties to report to the Pressure Vessel Standards Body all incidents involving major cracking of pressure parts (this could be defined by the Standards Body in terms of the length of repair needed) when such incidents did not involve injury or explosion.

12.24 Another aspect of importance to Standards is that the background of the various rules contained in Standards should be recorded and made available when such rules come up for revision or reconsideration. It is of value to the practising engineer and fabricator for the technical background of such rules to be published whenever possible. Although on occasion there may be commercial or political arguments against such publication, nevertheless the Committee considers publication of the technical background to such rules as essential. It is also possible in some instances to associate Standards with data sheets issued independently—for example the current series of Engineering Data Sheets.

We therefore recommend that

(i) the Government considers the views of the Committee of Enquiry expressed in paragraphs 12.20 to 12.24 and takes appropriate action;

(ii) the Pressure Vessel Standards Body takes note of the views of the Committee expressed in paragraphs 12.20 to 12.24 and takes appropriate action.

CHAPTER 13

A proposal for a national pressure vessel authority

Aims

13.1 The advantages accruing through having a co-ordinating body for Pressure Vessel Research are discussed in Chapter 9; the advantages from having a central body governing pressure vessel inspection during manufacture are discussed in Chapter 11; and the advantages from having a single Pressure Vessel Standards Body are discussed in Chapter 12. All of these activities are closely related. The inspection organisation must interpret the Standards, so that appeals for code-case interpretations are likely to involve both inspection and Standards aspects. Changes in design stress level and of manufacturing procedures or materials are likely to affect inspection requirements, whilst there is feedback of inspection experience to Standards. With regard to R & D it is necessary to modify Standards to permit new processes as quickly as possible; this would be easier if Standards and inspection aspects were considered during the work. Moreover in many cases proposals for R & D work would arise during Standards or inspection activities. Combination of these activities into one organisation is thus desirable technically and can lead to economy of structure.

13.2 Other activities which could with value be included in this organisation are the assessment and registration of fabricators, the arrangement of appropriate training and certification of personnel working in the pressure vessel industry including inspectors, and the co-ordination and presentation of UK viewpoints at international fora including those involving inspection and design standards.

13.3 It appears appropriate that the approval of fabricators, inspectors and other types of personnel by the organisation would provide a definition of the term 'competent organisation' or 'competent person', where this expression was used in certain regulations and Standards. An extension of this concept would be for the organisation to be invited by the Minister of Employment and Productivity to draft and interpret technical aspects of regulations on the Minister's behalf regarding the design, construction, installation, testing, and examination of boilers and pressure vessels and, also on the Minister's behalf, to define and approve the 'competent persons' to carry out such tests and examinations as may be appropriate at intervals in their service, as well as during manufacture. Finally the organisation could take note of any failures, accidents or explosions as noted in paragraph 12.23.

Nature of proposed organisation

13.4 It is suggested that the organisation be called the Pressure Vessel Authority (PVA) and that it be a public organisation, set up by, and reporting to the Minister of Technology, but be independent of his department. It should be non-profit making, and be financed by the industry and the Government as well as from fees charged for its various approval services.

13.5 The Committee considers that the organisation of the PVA should be as simple as possible, and the number of permanent staff should be kept to the minimum compatible with fulfilling the duties described in this chapter. It is proposed that a full-time professional Director be appointed by the Minister. The effectiveness of the PVA will depend greatly on the vigour, impartiality and technical experience of the Director, particularly during the first few years operation of the organisation. The Director will have to be selected with great care, and offered a salary sufficient to attract an individual with the required high level capabilities.

13.6 It is proposed that the PVA should have three principal divisions. The Technical Division would deal with all aspects of the preparation and modification of Standards on a national and international basis. This would include appeals and code-case reviews, and other aspects detailed in Chapter 12. The Research and Development Division would deal with all aspects of collaboration on research, with advice to SRC and other external research-initiating bodies, with exchange of information and with dissemination of research results. Particular attention would be given to developing pilot schemes and proving tests to ensure industrial application of research. The duties of this division are discussed in more detail in Chapter 9. The Authentication Division would be responsible for the arrangements for assessment and authentication of manufacturers, of inspection organisations, and of individual inspectors. It will pay particular attention to developing common standards of acceptance and to reducing duplication of inspection. These activities are discussed in detail in Chapter 11.

13.7 A suitable arrangement would be for each of these divisions to be run by an executive committee made up of a Chairman and some half dozen members for all of whom this would be a part-time occupation. They would be individuals selected for their professional standing and expertise on different aspects of pressure vessels; in particular the Chairmen would have to be evidently impartial. It must be emphasised that these committees are intended to be working committees, meeting frequently and regularly and taking the decisions necessary to ensure speedy and effective working of their divisions. They would be responsible for setting up and controlling the progress of working committees on particular topics. For example the Technical Committee would arrange for various working committees appropriate to the various Standards. In these cases, standing committees to deal with drafting, revision, code-case appeals and tentative specifications would be appropriate; while instructions on and timetabling of all of these aspects would be provided by the Technical Committee. In other cases it will be preferable to have working committees with limited objectives and limited periods of life. The working committees should be small, and the members selected on an individual rather than a representative basis, as discussed in paragraph 12.10. Topics on which the working committees failed to reach a decision would be referred quickly to the appropriate Divisional Committee for a ruling.

13.8 It is suggested that the different aspects of the operation of the PVA should be supervised by an Executive Board comprising the Director, the Chairmen of the three Divisions, and the Chairman of the Advisory Council (see paragraph 13.9). This would determine the policies of operation, the distribution of work and of resources between the divisions, provide for effective liaison both internally and externally and act in most cases as the final arbiter on decisions needed by, and on appeals made against, working committees. It may be necessary to provide for an appeal, in exceptional cases, to the Minister of Technology who could arrange for external arbitration.

13.9 To ensure receipt of viewpoints from all in the pressure vessel industry including designers, materials manufacturers, fabricators, inspectors, contractors, users, research workers, professional bodies, learned institutions and relevant government departments, it is proposed that an Advisory Council be set up comprising representatives named by the appropriate organisations. The important aspects of the working of the PVA will be reported to this Advisory Council and its comments invited on such reports and on any other relevant topics. The Council could conveniently report to the Executive Board, of which the Chairman of the Advisory Council should be a member. The Council would provide a mechanism for seeking advice on the membership of working committees and on those aspects of work needing attention.

13.10 The Director and the various Committees would need to be supported by professional, secretarial and administrative staff. Some of these would be full-time permanent employees of the PVA. Others could be attached to the PVA from government departments and establishments or other appropriate organisations to help with particular tasks, such as detailed drafting of Standards or the arranging of particular research programmes or carrying out the assessment of an organisation for the Authentication Committee. In this last respect, for example, use could be made of members of the AID organisation. It is not possible to indicate the numbers and nature of the full-time and attached staff required until the organisation is detailed further.

13.11 It is of course essential that on initiation of activity by the PVA, all existing organisations should cease activities which overlap with it. Such aspects will have to be covered by the legislation or other instruments by which the PVA is established. It would be necessary to hold discussions with relevant organisations and departments before preparing a detailed framework for the organisation, when its method of operation and legal responsibilities may be more closely defined. The Committee considers that the preceding paragraphs indicate a reasonable and preferred basis for these discussions. It is desirable that a Director be appointed at an early stage so that he may play his full part in the creation of the organisation, the choice of staff and of part time Chairmen, and in the selection of immediate objectives.

We therefore recommend that

(i) the Government takes the necesssry action to form a new organisation (the Pressure Vessel Authority) to supervise the preparation and modification of Standards, the authentication of fabricators and inspection organisations, and the collaboration on both research and development and on application of results;

(ii) a Director suitable for running such an organisation be appointed speedily, so that he may assist in the discussions and detailed preparations along the lines discussed in this Chapter.

CHAPTER 14

Legislation, international relations and other matters

Legislation

14.1 The present position on legislation in the UK relating to pressure vessels and their use is summarised in Appendix R. This Appendix also indicates the alterations in UK legislation which are currently (1968) being discussed and briefly surveys the statutory position abroad.

14.2 The UK is one of the few major industrial countries which does not embody within legislation any particular national design standard for pressure vessels. The Committee considers that the incorporation of, or specific reference to, detailed standards in legislation should be avoided as such practice can inhibit technical innovation. Provided that a 'competent' inspection organisation considers that a vessel is safe to work between its specified examinations it may be constructed to any design standard. The present UK legislation for vessels does not give a detailed definition of how 'competency' shall be established, nor does it require assessment of fabricators or of inspection services. This lack of definition does not necessarily imply laxity; indeed the situation can be more demanding on inspection requirements but less limiting on freedom of design than that required by a mandatory design standard.

14.3 The Committee considers that the PVA organisation proposed in Chapter 13 could define and assess competency in these areas, and suggests this be recognised in the forthcoming revisions to existing legislation (see paragraph 13.3). The PVA would be an appropriate body to supervise, on behalf of the Minister of Employment and Productivity, all of the activities described in paragraphs 34–36 of Appendix R.

14.4 A wide range of pressure vessels do not come under the requirements of the 1961 Factories Act. The Committee notes with satisfaction that the proposed revisions are intended to cover the whole pressure vessel field.

14.5 The multiplicity of requirements for reporting accidents involving pressure vessels was commented on in paragraph 12.23 in which a recommendation was made that all failures or incidents involving significant cracks or subsequent major repairs to pressure vessels, even when these incidents occur before commissioning, should be reported to the PVA. The Committee hopes this will be covered in the revised legislation. There may well be other aspects of the Report of the Committee of Enquiry which could require changes to existing legislation.

We therefore recommend that

> the Minister of Technology arranges for the Report of the Committee of Enquiry to be studied by those responsible for considering modifications to existing legislation.

Transport of pressure vessels

14.6 The maximum size and weight of large loads, including pressure vessels, that can be transported by road or rail are restricted. The regulations relating to road transport are summarised in Appendix J. For 'indivisible' loads the maximum sizes are: length 90 ft, width 20 ft, gross weight 150 tons, special permission being needed from the Ministry of Transport for widths exceeding 14 ft. These transport limitations must obviously be considered in relation to the rationalisation of the pressure vessel industry discussed in paragraph 7.24.

Insurance and post-commissioning inspection

14.7 Not many comments relating to insurance were received in the various submissions to the Committee. One submission suggested that the insurance companies should introduce more selective scales of premiums whereby the experienced users of pressure vessels could be charged at lower premiums than the less experienced or less expert users. Brief notes on insurance are given in Appendix S.

14.8 Unlike pre-commissioning inspection, the examinations of vessels at intervals throughout their service are frequently made under contracts linked with those for insurance. These examinations may also be required by legislation to be made by a 'competent' person, and we have suggested (see paragraphs 13.3 and 14.3) that this competency be defined by the PVA procedure.

14.9 The requirements for post-commissioning inspection can also affect Standards. For example, these should cover the positioning of platforms and ladders for access purposes, and should detail the sizes, positions and covering of manholes. Not only must access under normal conditions of inspection be considered, but it is also necessary to ensure that there is satisfactory access for inspectors with breathing equipment or other protective clothing, and consideration should be given to requirements that would facilitate rescue of inspectors in the event of sickness or injury. There are thus several aspects involving liaison between the PVA and the insurers, the inspection services and the Government Departments involved in administering the Factories and other relevant Acts. These points require more discussion when considering in greater detail the organisation of the PVA (see Chapter 13).

Information on failures

14.10 Various submissions to the Committee of Enquiry drew attention to specific pressure vessel failures and the lessons that could be learnt from these. It was apparent that some of these failures could have been avoided by improved communication, both between different organisations or companies and within individual companies, especially between the personnel directly involved in fabrication. The present method for altering Standards as a result of failure experience was slow and uncertain. For these reasons the Committee proposes the changes recommended in paragraph 12.23. Adoption of this recommendation should ensure that the PVA can quickly adapt Standards to cover lessons learnt from failures. There are, for example, design modifications still to be built into Standards from past failure experience. Several examples were given in a symposium held by the West of Scotland Iron and Steel Institute in Glasgow on the 17th May 1968.

We therefore recommend that

> the Ministry of Technology should sponsor a critical review of pressure vessel failure experience, covering all recent failures and major defects that have occurred either before or during service, with a view to developing authoritative recommendations on what changes in Standards should be made as a result of lessons learnt from such failures.

14.11 A useful source of information on failures and defects would be the insurance and inspection organisations. The Committee has been informed of a survey of defects in pressure vessels, made to high standards of construction, being undertaken during 1968 by AOTC in collaboration with the CEGB and the UKAEA (Authority Health and Safety Branch). This survey had, up to June 1968, received only 11 reports of serious defects arising during construction out of some 12 700 vessels under consideration. With regard to failures or defects occurring in service, some 140 cases were reported, from service records relating to over 100 000 vessel-years. These defects were mainly located by visual inspection. Cracks were the most common form of defect, over a third of these occurring at branches or fillet welds. This survey is continuing in greater detail and the Committee hopes that the eventual report would be published.

National and international activities on pressure vessel topics

14.12 Some details of the various UK activities relating to pressure vessels are given in Appendix T. The complex structure of BS Committees on pressure vessels, involving many working committees reporting to six different industry committees, with additional advisory co-ordinating committees (the E/–/3 series), has been criticised in Chapter 12. The lack of a single trade association to cater for pressure vessels has been emphasised in paragraph 3.12, and the multiplicity of inspection interests has been discussed in Chapter 11. With regard to learned societies, discussions on pressure vessels have been organised by the Institution of Mechanical Engineers, the Welding Institute, and the West of Scotland Iron and Steel Institute. There is no single research association or research centre for work specifically on pressure vessels, although the BWRA (now the Welding Institute) has worked extensively in this field. The Committee has made recommendations in this Report which will simplify these arrangements. In particular, the PVA proposed in Chapter 13 would provide overall co-ordination of all these activities.

14.13 International activities on pressure vessel topics are also diverse and complex (see Appendix U). The most important is that of ISO/TC11 which has already produced an international Recommendation on boilers and is engaged on a Recommendation for pressure vessels. Other relevant ISO committees are ISO/TC85/SC6 (steel nuclear pressure vessels) and ISO/TC58/SC3 (gas cylinders). The European Standards Co-ordinating Committee has been active in respect of air receivers (CEN/WG23), and a Tripartite Committee for Standardisation (representing France, Germany and the UK) discussed pressure vessel topics in October 1967. The European Economic Community has issued a proposed general directive to its member countries on pressure vessels (see Board of Trade Library Translation Service 3627–9/66/BJH/French), which includes proposals for an EEC Inspection Stamp. No similar proposals have yet been made by the EFTA countries, but in 1967 the EFTA Secretariat circulated proposals prepared by the Syndicate de l'Industric European des Bouteilles a Gaz Soudecs (SEBS) regarding welded gas-cylinders. Other relevant European organisations are the Association of European Inspection Organisations (CEOC) and the Comité Européen de la Chaudronnerie et de la Tôlerie (CECT) which gathered the views of pressure vessel fabricators from the six EEC countries and seven EFTA countries and advised ISO/TC11 accordingly. A number of the submissions to the Committee of Enquiry, whilst supporting the concept of rationalisation of design Standards on an international basis, commented critically on the number of international bodies involved, and on the difficulties of arranging UK representation and of co-ordinating this representation. The Committee of Enquiry considers that the proposed PVA organisation (see Chapter 13) could provide the necessary co-ordination and strengthen the voice of the UK in international discussions.

14.14 The development of international standards can take a long time—the ISO boiler Recommendation took about 15 years. Whilst less time would be anticipated in order to produce the Pressure Vessel Recommendation (which was first proposed in 1962) in view of common features with the Boiler Recommendation, nevertheless at the October 1967 meeting of ISO/TC11 it did not appear that agreement was imminent. It is therefore important that UK Standards are not held back to await agreement on ISO Recommendations and, whatever standards may be necessary to comply with international Recommendations, there should always be national UK Standards which permit designs to be commercially competitive with those permitted by other countries. This aspect was discussed in paragraph 12.20.

CHAPTER 15

Concluding comments

15.1 The purpose of this final chapter is to emphasise those aspects which the Committee considers of most importance in improving the efficiency and competitiveness of the UK pressure vessel industry.

15.2 The Committee believes that an active and efficient pressure vessel industry is an essential part of the industrial life of this country. This industry plays a major role in developing skills in heavy fabrication in general, and to quote only one example, the development of nuclear energy has relied significantly on skills arising from the pressure vessel industry. Pressure vessel technology plays an important role in many aspects of chemical engineering, petro-chemicals and power production. A strong indigenous pressure vessel industry can be of great help to these industries and their associated contracting organisations, whilst these industries have played an important part in UK exports. It is in the interests of these industries and contractors to encourage the UK pressure vessel industry towards further development so as to continue to meet their requirements. This may be done by discussion and by appropriate control of their buying policies.

15.3 The most important conclusion of the economic survey is that, over the next ten years, or even to the extent of the foreseeable future, it is unlikely that the UK vessel demand would exceed the peak demand achieved in 1966. If the pressure vessel industry is to develop, or even to remain effective at its present size, it will have to increase its export activity. This must have a major influence on the direction of development of the industry; it has influenced many of the recommendations of the Committee. Because many countries can make simple, mild steel vessels, an emphasis in the UK on exports implies greater emphasis on the more technologically-developed vessels, on advanced designs, and on the newer materials of construction.

15.4 The above comments are particularly important with regard to rationalisation of the pressure vessel industry. The situation in 1966 was one of a large number of companies, many of them small in pressure vessel output and in overall capacity. Whilst such small fabrication shops can operate with low overheads and so be more satisfied with their current profit margins, they generally restricted their activities to run-of-the-mill mild steel vessels and were not the most suited for technological development. The special equipment, facilities and skills required for the more advanced vessels, on which long-term export success will rely, can only be achieved economically by large units with suitable specialisation within a group. This is the background to the proposals for rationalisation in Chapter 7. Such rationalisation would bring many other advantages, especially if it were to be associated with the provision of modern, well-planned shops. Many of these changes require investment of capital, and this can be difficult to attract to an industry which shows such a low profit margin as does the pressure vessel industry.

15.5 A major problem arises from the pronounced variation in work-load for the industry, and this has varied by a factor of three over a period of several years. It is essential that other sections of UK industry, and especially the Government, take all possible steps to reduce this cyclic loading. For example, control of timing of orders from the public sector to provide counter-cyclical investment could be most helpful.

15.6 It is emphasised that many of the problems reported to the Committee during its initial work arose from the large increase in demand for pressure vessels in 1966. The Committee considers that the industry in fact made a very creditable effort to deal with this increased demand and that the level of imports during 1966 and the various complaints then made were not surprising in the circumstances. By mid-1967, these circumstances had completely changed, so that the industry was faced with different problems. In a similar way, the frequency of problems of steel supply reported by the fabricators reduced significantly with reduction in loading of the steel-works.

15.7 The steel plate used by the pressure vessel industry must fulfil several specialised requirements. In the UK this plate has been produced largely by steelplant associated with bulk-steel production. A particular problem is that of obtaining material sufficiently clean to satisfy the fabricators. The Committee considers that the 20% premium charged by the steelmakers for full ultrasonic inspection of steelplate has operated against the best interests of both the fabricators and the steel industry, and recommends that it be very much reduced. It is hoped that the vacuum-degassed steel-plate, which is becoming available in quantity at a premium of only £2 per ton, will provide the solution to these problems.

15.8 The pressure vessel industry has suffered in many ways from poor communications. There was (in 1968) no single organisation which could express the views of the pressure vessel industry, indeed this industry could not be regarded as an organised entity as could other industries. The Committee recommends (paragraph 3.13) that one trade association (TIPA) should be recognised as representing the pressure vessel industry and that it should form a special division to do this.

15.9 The Committee considers that the pressure vessel industry has suffered from the slowness in the preparation and modification of standards. The ability of the permanent staff of the BSI is recognised, but they are considered to be too few in number and to be burdened with too cumbersome a system. In particular, the attempt to produce standards that are unanimously agreed by large committees of representatives has led to delays and permitted influence by minority opinion. The resulting lack of confidence in obtaining speedy results has hampered support of BSI committees by the appropriate experts. Major changes are recommended by the Committee of Enquiry in the procedures for preparing pressure vessel standards (Chapters 12 and 13). The adoption of 'code case appeal' and 'tentative specification' procedures will help to provide flexible and up-to-date standards.

15.10 In respect of R & D, the Committee considers that the overall expenditure on R & D is of the right order, although much of this is devoted to work related to immediate contracts. The work suffered from lack of collaboration both in the planning and in the dissemination of the results; this applied over the whole spectrum of R & D from applied work at the fabricators to more basic work at the universities. The Committee recommends the formation of an R & D Committee, preferably to form part of the PVA, to remedy this and related problems (Chapters 10 and 13). The importance of encouraging the application of R & D results and of improving technology at the shop-floor level is stressed. In particular, Government action is deemed desirable to encourage innovation and to help cover the financial risk in industrial proving trials of new techniques or materials.

15.11 The major recommendation to which the Committee attaches considerable importance relates to the formation of a Pressure Vessel Authority (Chapter 13). The PVA will occupy a central position with respect to recommended changes in inspection services, in research and development, in the preparation of pressure vessel standards, in the co-ordination of national and international activities, and in respect of statutory and standards requirements. The PVA should be an independent public body, responsible to the Minister of Technology, with its permanent staff limited to the minimum necessary to carry out its supervisory assessments and other functions. Detailed recommendations are made to reduce multiplicity of inspection services, and to reduce differences between the requirements of different inspectors. The recommendations include assessment by the PVA of inspection organisations and registration of individual inspectors; and these activities would also help with regard to statutory requirements and international activities.

APPENDIX A

Organisations, companies and individuals providing written or other evidence

1. **Government departments**

   Board of Trade
   Department of Economic Affairs
   Department of Employment and Productivity
   Home Office
   Ministry of Defence
   Ministry of Power
   Ministry of Public Buildings and Works
   Ministry of Technology
   Ministry of Transport

2. **Public bodies (or Government-aided bodies)**

   British Iron and Steel Research Association
   British Non-Ferrous Metals Research Association
   British Standards Institution
   British Steel Corporation
   British Welding Research Association
   Central Electricity Generating Board
   East Midlands Gas Goard
   Electrical Research Association
   Gas Council
   National Computing Centre
   National Economic Development Office (Mechanical Engineering EDC)
   National Economic Development Office (Process Plant Working Party)
   National Ports Council
   National Research Development Corporation
   Production Engineering Research Association
   Science Research Council
   South of Scotland Electricity Board
   United Kingdom Atomic Energy Authority

3. **Professional institutions**

   Institute of Welding
   Institution of Chemical Engineers
   Institution of Engineering Inspection
   Institution of Gas Engineers
   Institution of Industrial Safety Officers
   Institution of Mechanical Engineers
   Institution of Production Engineers

4. **Trades and profesional unions**

   Amalgamated Society of Boilermakers
   Constructional Engineering Union
   Draughtsman's and Allied Technician's Association
   Engineer Surveyors Association
   National Register of Engineer Surveyors
   Trades Union Congress

5. Trade and independent organisations (materials, manufacturing, inspection, consulting and users)

Alloy and Stainless Steel Conference
Associated Offices Technical Committee
Association of Shell Boilermakers
British Chemical Engineering Contractors Association
British Chemical Plant Manufacturers Association
British Compressed Air Society
British Electrical and Allied Manufacturers Association
British Heavy Steel Association
British Hot Finished Tube Conference
British Insurance Association
British Iron and Steel Federation
British Steel Tube Conference
Chemical Industries Association
Confederation of British Industry
Copper Development Association
Council of British Manufacturers of Petroleum Equipment
Engineering Equipment Users Association
Lloyds Register of Shipping
National Forgemasters Association
Oil Companies Materials Association
Sheet Makers Conference
Society of British Gas Industries
Society of Chemical Industry
Tank and Industrial Plant Association
Tube Steel Association
Water Tube Boilermakers Association

6. Companies

Adamson and Hatchett Limited
Air Products Limited
Alcan Industries
Aluminium Federation
A.P.V. Company Limited
Appleby-Frodingham Steel Company
Ashmore, Benson, Pease and Company Limited
Associated Electrical Industries Limited
W. S. Atkins and Partners
Atomic Power Construction Limited
Babcock and Wilcox Limited
Henry Balfour and Company Limited
Barr Thompson and Company Limited
Bristol Aerojet Limited
Bristol Piping Company Limited
British Aluminium Company Limited
British Oxygen Company Limited
British Petroleum Company
Brown Bayley Steels Limited
W. P. Butterfield (Engineers) Limited
Caltex Services Limited
Cammell Laird and Company
Chesterfield Tube Company Limited

Clayton Son and Company Limited
Colvilles Limited
Consett Iron Company Limited
Constructors John Brown Limited
Courtaulds Limited
A. F. Craig and Company Limited
Cremer and Warner
Edwin Danks and Company
Davey and Paxman and Company Limited
Davy United Engineering Company Limited
Distington Engineering Company
Dorman Long (Steel) Limited
Drury Engineering Company Limited
Eagle Star Insurance Company Limited
English Electric Arc Welding Company Limited
English Electric Company Limited
English Steel Corporation Limited
English Steel Forge and Engineering Corporation Limited
ESAB Limited
Esso Petroleum Company Limited
Eutectic Welding Alloys Company Limited
Firth Brown Limited
Foster Wheeler and John Brown Boilers Limited
Samuel Fox and Company Limited
M. and W. Grazebrook Limited
Hadfields Limited
G. G. Harvey and Company
Harvey Fabrication Limited
Head Wrightson (Teesdale) Limited
Heat Transfer Limited
W. C. Holmes
Horseley Bridge and Thomas Piggott Limited
Humphreys and Glasgow Limited
Imperial Chemical Industries Limited
Imperial Metal Industries (Kynoch) Limited
International Combustion Limited
International Nickel Limited
Robert Jenkins Limited
Jessop-Saville Limited
A. Johnson and Company (London) Limited
Longclose Engineering Company Limited
Metal Propellers Limited
Metrode Products Limited
L. A. Mitchell Limited
Robert Morton and Company Limited
Motherwell Bridge and Engineering Company Limited
Murex Welding Processes Limited
William Neill and Son Limited
Newton Chambers Engineering Limited
Nuclear Design and Construction Company Limited
Nuclear Power Group Limited
Oerlikon Electrodes (GB) Limited
Old Park Engineering Limited
Olin Mathieson Limited
Philips Welding Limited
Power-Gas Corporation Limited

Redheugh Iron and Steel Company Limited
Rendell, Palmer and Tritton
Richardsons Westgarth and Company Limited
Rockweld Limited
Rolls-Royce and Associates Limited
J. T. Rothwell and Company Limited
Round Oak Steel Works Limited
Ruston and Hornsby Limited
Simon Carves Limited
Soudometal UK
South Durham Steel and Iron Company Limited
Staffordshire Services Engineering Company
Stainless Steel Plant Limited
Steel Company of Wales
Steel Peech and Tozer Limited
Stewarts and Lloyds Limited
John Summers and Sons Limited
The Superheater Company Limited
Richard Thomas and Baldwins Limited
The John Thompson Group and Engineering Company Limited
Unilever Limited
United Steel Company
G. and J. Weir Limited
Wellington Engineering Works Limited
Wellman Incandescent Furnace Company Limited
Whessoe Limited
Woodall Duckham Limited
Yorkshire Engineering and Welding Company Limited

7. Academic institutions

Aston University
Bath University
Birmingham University
Bradford University
Bristol University
Brunel University
Cambridge University
City University
Durham University
Exeter University
Glasgow University
Imperial College of Science and Technology
Leeds University
Leicester University
Liverpool University
Loughborough University
Manchester Institute of Science and Technology
Manchester University
Newcastle upon Tyne University
Nottingham University
Oxford University
Queen's University, Belfast
Salford University
Sheffield University

South Wales and Monmouthshire University College, Cardiff
Sussex University
University College
University College of Wales, Swansea
Welsh College of Advanced Technology

8. Individuals

Mr. H. L. Carson (CERL)
Mr. J. A. Derry (English Electric Company Limited)
Ing. J. H. Donker (Dienst Voor Het Stoomwezen, Holland)
Mr. J. Eyers (AOTC)
Dr. H. Fessler (Nottingham University)
Prof. H. Kihara (University of Tokyo)
Mr. J. F. Lancaster (Kellogg International Corporation)
Mr. J. J. Whenray (THE, BSI)

APPENDIX B

List of acronyms

ACE	Association of Consulting Engineers
ADN	The International Agreement on the Transport of Dangerous Goods by Inland Waterways
ADR	The International Agreement on the Transport of Dangerous Goods by Road
AEU	Amalgamated Engineering Union
AF	Aluminium Federation
AID	Aeronautical Inspection Directorate
AOTC	Associated Offices Technical Committee
ASB	Association of Shell Boilermakers
ASME	American Society of Mechanical Engineers
BASEEFA	British Approvals Service for Electrical Equipment in Flammable Atmospheres
BCAS	British Compressed Air Society
BCECA	British Chemical Engineering Contractors Association
BCPMA	British Chemical Plant Manufacturers Association
BCS	British Calibration Service
BEAMA	British Electrical and Allied Manufacturers Association
BHFTC	British Hot Finished Tube Conference
BHSA	British Heavy Steel Association
BIA	British Insurance Association
BISCO	British Iron and Steel Council
BISF	British Iron and Steel Federation
BISPA	British Iron and Steel Producers Association
BISRA	British Iron and Steel Research Association
BNEC	British National Export Council
BNFMRA	British Non-Ferrous Metals Research Association
Boilermakers	Amalgamated Society of Boilermakers
BOT	Board of Trade
BR	British Railways
BSC	British Steel Corporation
BSI	British Standards Institution
BSRA	British Ship Research Association
BWRA	British Welding Research Association
CA	Chemical Age (Journal)
CAD	Computer Aided Design
CBI	Confederation of British Industries
CBMPE	Council of British Manufacturers of Petroleum Equipment
CDA	Copper Development Association
CECT	Comité Européen de la Chaudronnerie et de la Tôlerie (European Association of National Boiler and Pressure Vessel Trade Associations)
CEGB	Central Electricity Generating Board
CEN	Comité Européen de Coordination des Normes (European Standards Coordinating Committee)
CEOC	Colloque Européen des Organismes de Contrôle (Association of European Inspecting Organisations)
CEPT	Centre de Productivité de la Chaudronnerie et de la Tôlerie

CEPV	Committee of Enquiry on Pressure Vessels
CEU	Constructional Engineering Union
CHE	Chemical Engineering Industry
CIA	Chemical Industries Association
CIF	Carriage, Insurance, Freight
CIM	The International Convention Concerning the Transport of Goods by Rail
COMECON	Council for Mutual Economic Assistance
Committee	Committee of Enquiry on Pressure Vessels
CSA	Canadian Standards Association
DATA	Draughtsmans' and Allied Technicians' Association
DEA	Department of Economic Affairs
DEP	Department of Employment and Productivity
DNA	Deutscher Normanausschuss (German Standards Organisation)
EC	Electricity Council
ECGD	Export Credit Guarantee Department
EEC	European Economic Community
EEF	Engineering Employers' Federation
EEUA	Engineering Equipment Users' Association
EFIM	Ente Autonome di Gestione per le Parecipazioni del Fondo di Finanziamento dell' Industria Meccanica (Italian)
EFTA	European Free Trade Association
EID	Electrical Inspection Directorate
ENEL	Italian Electricity Generation Authority
ENI	Italian Oil Industry Authority
ERA	Electrical Research Association
ESA	Engineer Surveyors' Association
FF	French Francs
FOB	Free on Board (ships)
FTE	Fracture Transition Elastic Temperature
FTP	Fracture Transition Plastic Temperature
GATT	General Agreement on Tariffs and Trade
GAPAVE	Groupement des Associations de Proprietaires d'Appareils à Vapeur et Electriques
GC	Gas Council
HE	Heat Exchanger
HFS	Heavy Fabrication Shop
H.O.	Home Office
HPG	High Pressure Gas
HTS	Heat Transfer Society
IChE	Institution of Chemical Engineers
IIW	International Institute of Welding
I Mech E	Institution of Mechanical Engineers
IRC	Industrial Reorganisation Corporation
IRI	Istituto per La Reconstruzione Industriale (Italian)
ISE	Iron and Steel Industry
ISI	Iron and Steel Institute
ISO	International Organisation for Standardisation
IW	Institute of Welding

JPS	Joint Parliamentary Secretary
Lloyds	Lloyds Register of Shipping
LNG	Liquified Natural Gas
LPD	Light Petroleum Distillate
LPG	Low Pressure Gas
m	Metre
mm	Millimetre
M	Million
mcfd	Million cubic feet per day (gas consumption)
MEE	Mechanical Engineering Industry
MEEDC	Mechanical Engineering Economic Development Committee
MIG	Metal (Inert Gas) Arc Welding Process
Mintech	Ministry of Technology
MITI	Ministry of International Trade and Industry (Japan)
MOD	Ministry of Defence
MOP	Ministry of Power
MOT	Ministry of Transport
MPBW	Ministry of Public Building and Works
mtce	Million tons coal equivalent (fuel consumption)
NCB	National Coal Board
NCC	National Computing Centre
NCE	Nuclear Energy Industry
NDACSS	Navy Department Advisory Committee on Structural Steels
NDT	Nil Ductility Transition Temperature
NDT	Non Destructive Testing
NEDC	National Economic Development Committee
NEDO	National Economic Development Office
NEL	National Engineering Laboratory
NFA	National Forgemasters Association
NIA	National Inspection Authority
NPL	National Physical Laboratory
NRDC	National Research Development Corporation
NRES	National Register of Engineer Surveyors
OCMA	Oil Companies Materials Association
PEE	Petroleum Equipment Industry
PERA	Production Engineering Research Association
PPWP	Process Plant Working Party
PV	Pressure Vessel
PVA	Pressure Vessel Authority
PVRC	Pressure Vessel Research Committee
RID	The International Regulations Concerning the Transport of Dangerous Goods by Rail
RML	Reactor Materials Laboratory, Culcheth
SAA	Standards Association of Australia
SBGI	Society of British Gas Industries
SC	Spare capacity (in heavy fabrication shops)
SC	Steelmakers Conference
S Ch I	Society of Chemical Industry

SF	Swiss Francs
SIS	Standards Institute of Sweden
SSEB	South of Scotland Electricity Board
SW	Site-work (site erected pressure vessels and tanks)
T	Tank
TIG	Tungsten (Inert Gas) Arc Welding Process
TIPA	Tank and Industrial Plant Association
TSA	Tube Steel Association
TUC	Trades Union Congress
TUV	Vereingung der Technischen Uberwachungs-Vereine (German Federation for Technical Supervision)
UK	United Kingdom
UKAEA	United Kingdom Atomic Energy Authority
UTS	Ultimate Tensile Strength
VDMA	Verband Deutscher Maschinenbau—Anstalten (Federation of German Machinery Manufacturers)
WEE	Welding Industry
WTBA	Water Tube Boilermakers Association
YS	Yield Stress

APPENDIX C

Glossary of technical and industrial terms

1. List of Symbols used in report

Al	Aluminium
C	Carbon
Cr	Chromium
E_t	Tensile yield or 0·2% proof stress
k	Ratio of external diameter to internal diameter of a cylinder
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Ni	Nickel
p	Design pressure
p_b	Pressure at which widespread yield or 'ballooning' occurs
q	Design shear stress
q_y	Lower shear yield stress
R_t	Ultimate tensile strength (minimum)
S	Safety factor, or Stress

2. Glossary of terms used in report

Boiler	A steam boiler is any closed vessel in which for any purpose steam is generated under pressure greater than atmospheric pressure, and includes any economiser used to heat water being fed to any such vessel, and any superheater used for heating steam.
Boiler explosion	The Boiler Explosions Acts (1882 and 1890) are administered by the Board of Trade and provide for inquiries to be held in respect of explosions from boilers in the UK and in British ships. The owner of any boiler (with certain exceptions) from which an explosion occurs must report the fact to the Board of Trade, which assumes responsibility for any official investigation as to the cause of the explosion. Remedial action (if required) is initiated by the Chief Inspector of Factories, DEP, through the appropriate District Factory Inspector.
Brittle fracture	The tendency of a metal to fracture without appreciable deformation and at reduced stress.
Capacity	Pressure vessel production capacity as derived from the fabricator's estimates of how much more they could have produced, with the same equipment and labour situation, during 1966.
Cascade tax	A tax levied on the total selling price of an article each time the article is sold (including the various stages of manufacture and trade-dealing of the article). Alternatively described as turnover-tax.
Code case	See paragraph 12.18 for description.
Company	This term as used in the Report includes manufacturing or trading organisations styled 'firms'.

Competent person	Every thorough examination of a steam boiler (and indeed any pressure vessel) must be performed, for purposes of the Factory Acts, 1961, by a competent person. This phrase is not defined in the Act but the interpretation generally applied by the Factory Inspectorate is that a competent person is a person with such practical and theoretical knowledge and experience of the plant he has to examine as will enable him to detect defects or weaknesses and to assess their importance in relation to the strength and function of the plant in question. See also paragraph 13.3.
Consumables	See electrodes.
Contractors	For purposes of this Report the term 'contractors' is taken to include all those chemical and process plant contractors undertaking work which involves vessels, as well as contracting divisions of major plant users undertaking similar work.
Cranage	The maximum load that may be lifted by crane (as opposed to hydraulic jacks) in individual fabrication shops.
Demand	Unless otherwise indicated, demand data is quoted as vessel expenditures by purchasers or users in any one year. It thus represents payments made to fabricators for the delivery of completed vessels. It does not represent the value of orders placed with fabricators, nor does it represent the sanctions for expenditure made by customers or users. It will be appreciated that sanctions for expenditure predate actual expenditures by a margin of time, which for vessels is normally in the range from one to three years.
Demarcation	Interpreted as demarcation restricting the flexible use of skilled labour in respect of demarcation both between different unions and between different skills in the same union.
Design factor	An arbituary number with which the specified stress value for a material (yield, proof, or ultimate stresses either in shear or in tension) is divided to give the permitted design stress to be used in calculating vessel wall scantlings. It is commonly called the factor of safety or the factor of ignorance.
Design stress	The stress used as a basis for determining the thickness of a vessel wall given the vessel's working pressure, and itself determined by the specified material stress value and design factor according to the design standard or other specification employed.
Devaluation	This term refers to the devaluation of the pound sterling on the 18th November, 1967 from (\$2:80 to £1) to (\$2:40 to £1).

Direct production worker	Defined as: (a) Skilled: welders, platers, erectors, fitters, etc. accepted by the Boilermaker's Society, or equivalent union as having received a recognised apprenticeship or training; (b) Semi-skilled: non-trained for specific tasks other than through an apprenticeship, e.g. chippers-out, polishers, commercial welders and platers' mates. (c) Unskilled: any unskilled workers carrying out production tasks.
Dumping	There are several classes of dumping and full definitions are given in Appendix F (Chapter 12). Generally the dumping of goods arises whenever the goods are sold in a country different to that in which they are made, and at a price less than that for equivalent goods sold in the country of manufacture.
Electrodes	Welding consumables.
Exports	Unless otherwise stated, this means exports from the U.K. to other countries abroad.
Factor of ignorance	See design factor.
Factor of safety	See design factor.
Failure	The failure of a vessel, for the purposes of this Report, may arise from excessive deformation, from fracture, or from leakage. See also paragraph 10.20.
Fracture toughness	A measure of the degree of the resistance of a material against fracture.
Heat exchanger	Heat exchangers considered in this Report are those with a shell greater than $\frac{3}{8}''$ in thickness, built to a recognised vessel design standard.
Heavy fabrication shop	The heavy fabrication shop includes those bays, equipped with overhead cranes, plate forming, cutting and welding equipment, that can be used for heavy plate work. It also includes the annealing furnace and X-ray machine should these be outside the shop.
Hydraulic Test	See pressure test.
Hydrogen embrittlement	Hydrogen induced hard zone cracking.
Imports	Unless otherwise stated, this means imports into the UK from other countries abroad.
Indirect production worker	This includes such categories as crane-drivers, slingers, sweepers, store-keepers etc.
Inspection	For the purpose of this Report, the aspects of inspection considered are those arising during manufacture (including design approval and materials inspection where appropriate) up to and including commissioning. Detailed consideration of maintenance or 'in-use' inspection is not included in the present report.
Inspection organisation	Any independent inspection body, or inspection division of contractor or vessel manufacturer suitably constituted, competent to carry out inspections of vessels and their fabrication.

Inspectors	Employees (of inspection organisations) competent to carry out the inspection of vessels.
Insurance	The guaranteeing of vessels in use against accident or failure, normally through an arrangement for the payment of a sum of money in the event of loss or injury arising from a failure or accident in respect of the vessel(s).
Lamellar tearing	Opening of cracks along inclusion lines within steel plate due to stresses in the plates' 'through thickness' direction, and caused by welded-on attachments such as nozzles.
Legislation	Statutory provisions of Government, usually relating to health and safety in respect of the use of pressure parts.
Output per man	Gross sales output per heavy fabrication shop worker.
Pound Sterling	Unless otherwise stated, the monetary unit is the pound sterling prior to the devaluation of 18th November, 1967, since most of the statistical and economical data originated before that date.
Pressure test	The final pressure test undertaken before commissioning a vessel, normally undertaken as a hydraulic test.
Pressure vessel	All reactor vessels, storage vessels and columns built to a design standard (or specification) and/or subject to inspection requirements. It also includes certain other vessels intended to contain fluids at pressures greater than atmospheric pressure, designed and built to a design standard and/or subject to inspection requirements. Certain vessels outside the Committee's area of direct interest are listed in paragraph 1.5.
Pressure vessel industry	The pressure vessel industry is a loosely defined proportion of the heavy fabrication industry, and consists of those fabricators which make at least some pressure vessels.
Prices	Referred to in constant values or current values as indicated in the Report. See Appendix F (Chapter 1).
Process plant	Chemical plant, mineral oil refining plant, and other plant in which batch or (more often) continuous flow processes occur.
Production technical employee	See technical employee.
Productivity	Not used quantitatively in this Report, but normally taken as a measure of the added-value per man-year.
Profitability	Quoted in this Report purely as subjective views on profitability as expressed by the fabricators themselves.
Proof stress	That stress producing an arbitrary value of permanent strain, normally 0·2%.

Research	Relates to basic or objective research (as opposed to pure research).
R & D	For the purpose of the Report, R & D includes the whole spectrum of work ranging from basic research to fabrication process assessment following on the day-to-day changes in jobs in the shops. See paragraph 9.2.
Safety factor	See design factor.
Semi-skilled labour	See direct production worker.
Skilled labour	See direct production worker.
Tanks	Plate-welded tanks including storage vessels bulk transport containers/pressure vessels, etc with a capacity of more than 100 gallons, made from plate not less than $\frac{3}{8}''$ thick and of welded construction.
Technical employee	Includes: production engineers and any supporting technical staff; foreman; design draughtsmen capable of designing a complete pressure vessel from a specification; detail draughtsmen not originating designs; laboratory and testing staff; technical staff engaged in development work. Excludes: estimators, shop inspection staff.
TVA	Added-value tax, in which only the value added to the article being produced is liable to the payment of tax by the manufacturer, or alternatively on the additional element of the selling price of an article each time the article changes hands.
Ultimate tensile strength	The highest load applied to a metal in the course of a tensile test, divided by the original cross-sectional area of the tensile test piece.
Unskilled labour	See direct production worker.
Vessels	The generic term meaning pressure vessels, heat exchangers and tanks (both shop and site-built unless noted otherwise).
Welding	The joining of two pieces of metal by raising the temperature at the joint so that the metal may be united by hammering, pressure, friction or fusion. Includes: electric resistance; manual electric arc; automatic submerged arc; electro-slag; TIG; electron-beam; friction; and explosive welding.
Yield strength	The stress at which any further increase in stress would produce a permanent strain (or plastic deformation) in a metal.

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TABLE 5 Design standards (or codes) for pressure vessels in different countries as at January 1968

Country	National Pressure Vessel Code	Other Codes for Home Demand	Code Writing Body	Body responsible for Code Administration	Basis of Establishing Design Stress	Steels Acceptable for Code Construction		Mechanism for Acceptance of Steels	Legal Standing of National Code
						Designation	Standardising Body		
France	Réglementation des Appareils à Pression de Gaz (Unfired pressure vessels)	None except after modification e.g. ASME in refineries	Syndicat National de Chaudronnerie et Tôlerie	Service des Mines	$R_t/3$	Steel complying with the following formulae is acceptable (a) $R_{20}.d>900$ where R_{20} is in kg/mm² and d is %age elongation. (b) $d>12\%$	Association Française de Normalisation Groupement des Associations de Propriétaires d'Appareils à Vapeur et Electriques. Bureau de Normalisation de Sidérurgie	Steels are not required to be individually approved	Not a real code, no legal standing
Germany	AD Merkblätter (Unfired pressure vessels)	ASME below 350°C	Technische Ueberwachungsvereine	TUV	Lowest of $E_t/1·5$ $S_R/1·5, S_c{}^*/1·5$	DIN and VDEh steels listed plus those individually approved by TUV	Deutsche Normenausschuss (DIN standards) and Verein Deutscher Eisenhüttenleute (VDEh)	Proprietary steels are submitted for approval to TUV and accepted on the basis of satisfactory mechanical test results	Force of law
Italy	ANCC Code	ASME	Associazione Nazionale Controllo Combustione (ANCC)	ANCC	$E_t/1·5$ or $S_R/1·5$	Boiler and Pressure Vessel plate to UNI DIN and ASTM specifications are acceptable together with some designated proprietary steels from Italian Mills	Unificazione Italiana UNI	Steels are individually approved by ANCC	Force of law
Japan	Construction of unfired pressure vessels	ASME	Japanese Industrial Standards Committee	Industrial Manufacturers Inspection Institute delegates authority	$E_t/1·7$ $E_t/1·5$ for Al	Steels complying with JIS standard	JIS	Steels are individually approved by JIS	No legal standing
Sweden	Tryckkärlsnormer (Pressure Vessels)		Swedish Pressure Vessel Commission	National Board of Workers Protection (WPB)	$E_t/1·5$, but t not less than 150°C	SIS steels listed in the Codes	Sveriges Standardiserings Kommission (SIS)	Steels listed plus those individually approved by WPB	No legal standing but mandatory in practice
United Kingdom	BS 1500	ASME Sec. VIII	BSI	None. User or inspection agency is expected to supervise construction	$R_t/4$	Steels to BS specifications listed in code	British Standards Institution	A system for formal approval of materials is under consideration	Not legally mandatory, but use regarded as established practice and could provide legal defence
	BS 1515				$R_{20}/2·35$, $E_t/1·5$, $S_R/1·5$ or $S_c/1·0$	Steels to BS specifications listed in code. Other steels provided that elongation is greater than 16% for plate and 15% for other forms			
United States of America	ASME Code Sec. III (Nuclear vessels)	None	ASME	Inspection authorities of States and municipalities adopting code	$R_t/3$ or $E_t/1·5$	ASME specifications listed in code	ASTM/ASME	Steels standardised by ASTM are adopted by ASME perhaps slightly modified	Force of law where State has adopted code
	Section VIII				$R_t/4$, $E_t/1·6$ or $S_R/1·0$				
International	Draft Boiler Code, Pressure vessel code may be similar		ISO	National Inspecting Authority	$R_{20}/2·7$, $E_t/1·6$ $S_R/1·6$ or $S_c/1·0$	Registered national standards of ISO member countries	National standardising authority	National standards matching ISO may be registered with secretariat	Dependent entirely on national law

R_{20} = minimum ultimate tensile strength at room temperature

R_t = minimum ultimate tensile strength at operating temperature

E_t = minimum yield stress at operating temperature or, if YS not clearly defined, 0·2% proof stress at operating temperature

S_R = average stress for rupture after 100 000 hours at operating temperature

S_c = average stress for 1% creep after 100 000 hours at operating temperature

$S_c{}^*$ = average stress for 1% creep after 100 000 hours at operating temperature + 15°C